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## Four new species of *Arthothelium* (Arthoniales, Ascomycetes) from Africa and Socotra

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### Abstract

Four species of *Arthothelium* from Africa and Socotra are described as new to science: *Arthothelium atrorubrum* from Madagascar, characterized by irregularly rounded blackish ascomata with a deeply red hypothecium and submuriform ascospores; *Arthothelium aurantiacopruinosum* from the Democratic Republic of the Congo, characterized by black, irregularly rounded to stellate, orange pruinose ascomata and muriform ascospores with two larger terminal cells; *Arthothelium frischianum* from Madagascar, characterized by brownish-black minute irregular ascomata with remnants of thallus and muriform ascospores with one larger terminal cell; *Arthothelium miesii* from Socotra (Yemen), characterized by a thick thallus, immersed, stellate to cerebriform, brownish, greyish pruinose ascomata and submuriform ascospores. A key to all reported species of *Arthothelium* from tropical Africa (South Africa excluded) and Socotra is provided.

### Introduction

The genus *Arthothelium* A. Massalongo (1852: 54) has a cosmopolitan distribution, with the highest diversity in the tropics. Species occur on bark, especially on smooth surfaces in humid, little disturbed habitats, more rarely on rock and then mainly in coastal habitats with a Mediterranean or desert type climate. With the inclusion of *Mycarthothelium* Vainio (1928: 107) and *Allarthothelium* (Vainio 1896: 263) Zahlbruckner (1907: 241), the genus is known by ca. 136 species ([www.indexfungorum.org](http://www.indexfungorum.org)) and is in need of revision. Many nomenclatural changes have already been proposed by Santesson (1952) and subsequently by Makhija & Patwardhan (1985, 1995a). The study by Makhija & Patwardhan (1995b) of the genus in India resulted in the description of 21 new species and seven new records.

The genera *Arthonia* Acharius (1806: 3) and *Arthothelium* are characterized by a crustose thallus, rounded, maculiform or lirellate ascomata, a reduction of ascomatal border and a globose to clavate ascus type (Sundin *et al.* 2012; Frisch *et al.* 2014). The traditional morphological character to separate them is the ascospore septation: transversely septate in *Arthonia* and muriform in *Arthothelium* (e.g. Santesson 1952; Makhija & Patwardhan 1995b; Sundin & Tehler 1998; Sundin 1999; Grube 2007; Sundin *et al.* 2012). But not all lichenologists in the past have used ascospore septation as a generic character. For instance Nylander (1856, 1859, 1863a, 1868, 1869a and 1891) already included species with muriform ascospores in *Arthonia*. Many of those species were later on transferred to *Arthothelium*, mostly by Müller and Zahlbruckner (Zahlbruckner 1924). Coppins & James (1979) claimed that *Arthothelium* is undoubtedly composed of disparate groups of species that have evolved independently from corresponding species of *Arthonia*. Later, Grube & Giralt (1996) doubted the monophyly of *Arthothelium*, because several species placed in this genus due to their muriform spores are similar to *Arthonia* in other ascomatal characters. In 1998, Grube stated that the number of ascospores septa and the presence of longitudinal septa can certainly not be used alone to circumscribe monophyletic lineages within the family. In recent years molecular studies of Arthoniales have revealed that *Arthothelium* is polyphyletic, demonstrating that the previous classifications do not reflect evolutionary patterns (Frisch *et al.* 2014), with the type species *A. spectabile* A. Massalongo (1852: 54) placed in the cryptothecioid subclade (Frisch *et al.* 2015). Taxon sampling for molecular data in the Arthoniaceae are at present not sufficient to reallocate the *Arthothelium* species to other genera. Therefore, we have decided to follow the tradition to place species of Arthoniaceae with muriform ascospores in *Arthothelium* until sequence data of much more taxa become available.

Arthoniaceae in Africa and Socotra are poorly known, with *Arthothelium* represented so far by ca. 28 species, 17 species when South Africa is excluded (Baglietto 1875; Müller 1882, 1894a; Nylander 1886; Vainio 1901, 1929–1930; Steiner 1902; Doidge 1950; Beentje 1998; Mies & Schulz 2004; Seaward & Aptroot 2004; Aptroot & Wirth 2006; Schumm & Aptroot 2010). For eight other species, nomenclatural changes have already been proposed by Santesson (1952) and by Makhija & Patwardhan (1985, 1995a).

As part of taxonomic revisions of tropical Arthoniaceae, four new species of *Arthothelium* were discovered in both old herbarium material from Socotra and from the Congo Basin in the Democratic Republic of the Congo and in recently collected material from Madagascar. These three regions are well-known for their extraordinary biodiversity (Goodman & Benstead 2003; Brown & Mies 2012). The present study aims at describing these new species of Arthoniaceae.

## Material and Methods

Specimens were studied using a Wild M38 stereomicroscope and two Olympus CHR-TR45 and Olympus BX51 microscopes. Microscopical preparations were mounted in water, 5% KOH (K) and Lugol's reagent (1% I<sub>2</sub>), either without (I) or with KOH pre-treatment (K/I). Measurements of ascospores refer to material examined in water, those of asci to material examined in K/I. For measurements of asci, ascospores and conidia the minimum and maximum values are given, all values, except those of the conidia, rounded to the nearest multiple of 0.5 µm, followed by the number of measurements (N). Microchemical reactions and spot tests were performed using a 10% KOH, a sodium hypochlorite solution (C), *para*-Phenylenediamine (PD) and 25% H<sub>2</sub>SO<sub>4</sub> (for the detection of Calcium oxalate). Secondary metabolites were identified by TLC (solvent B) according to Orange *et al.* (2010).

Type specimens and non-type material of *Arthothelium* species (*Mycarthothelium* included) described from or mentioned to occur in Africa and Socotra were studied. Specimens were examined from the following herbaria: BM, BR, FR, G, H, KR, M, S, STU, TUR, US, WU. The original descriptions and those present on JSTOR (<http://plants.jstor.org>) of all *Arthothelium* species occurring outside Africa and Socotra were also examined to ensure that no older names were available for the new species. Additional specimens of *Arthothelium desertorum* Aptroot & V. Wirth (2006: 124) were studied for comparison with one of the new species (*A. miesii*). NAMIBIA. Lüderitz, Lüderitz peninsula, Kleiner Flord, close to the coast, on rock, 15–20 m, 26°42'58.81"S 15°05'26.85"E, 1 October 2009, *Wirth 41668* (STU), *Wirth 41726* (STU); *ibidem*, 30 September 2009, *Wirth 41394* (STU); District Omaruru, Central Namib Desert, Myl 72, Laguneberg, Nähe Gipfel, 153 m ü. M., 21°49'21.0"S 14°04'58.0"E, 22 May 2002, leg. Wirth V. & Heklau M., *Wirth 43061* (STU).

## Taxonomic treatment

*Arthothelium atrorubrum* Van den Broeck & Ertz *sp. nov.* (Fig. 1A–E)

Mycobank 822911

The new species differs from all other *Arthothelium* species by black ascomata with abundant red or purplish pigment in the hypothecium in combination with submuriform ascospores of 13–17 × 7–10 µm without larger terminal cells.

**Type:**—MADAGASCAR. Province Diego Suarez: Antsiranana, W of Sambava, Marojejy National Park, along trail from Camp Simpona to summit, rather dense humid montane forest grading into dense sclerophyllous upper montane forests, ca. 1600 m, 14°26'27"S, 49°44'23"E, 20 October 2014, *D. Ertz 20071* (holotype: BR!, isotype: TAN).

*Thallus* corticolous, crustose, whitish, sometimes with areas having a reddish to purplish tinge or speckled with reddish to purplish granules, continuous or rimose, slightly shiny, ca. 100–200 µm thick. *Prothallus* black. *Photobiont* not observed, doubtfully lichenized. *Ascomata* 0.35–2.5 × 0.25–1.75 mm, numerous, first immersed in the thallus, bursting through it to become sessile, irregularly rounded, sometimes shortly elongated or lobate, scattered more or less evenly over the thallus or grouped; disc black, frequently red or purplish at the margins or where the (epi)hymenium is abraded or cracked owing to abundant red pigment in the hypothecium, with or without a whitish pruina (probably consisting of remnants of thallus), unchanged when wet, shiny, ± rough, flat to slightly convex, without visible margin. *Excipulum* inconspicuous. *Epihymenium* 20–25 µm thick, with a dark brown layer formed by the tips of the interascal hyphae, K+ green. *Hymenium* 60–70 µm tall, hyaline to slightly brownish, not interspersed, I+ red, K/I+ blue. *Paraphysoids* hyaline,

some with distinct dark caps and walls, densely branched and netted, ca. 1–1.5 µm wide. *Hypothecium* 65–85 µm thick composed of red granules or crystals, K+ purplish, not dissolving, I+ red, K/I+ blue. *Asci* 17–19 × 16–18 µm (N = 5), globose to ovoid, without or with a very short stipe, 8-spored, some asci with broad or very small ocular chamber, with K/I+ blue ring like structure in the tholus. *Ascospores* 13–17 × 7–10 µm (N = 22), submuriform, hyaline, becoming dark brown (wall, including septa) when overmature, oblong, usually without enlarged terminal cell, with 3(–4) transversal and 1 longitudinal septa; *gelatinous sheet* ca. 0.5 µm; spore ontogeny macrocephalic, bidirectional. *Pycnidia* partly immersed in thallus, rare, forming conical-hemispherical projections, ca. 1.3 mm high, the ostiole sometimes visible, black, mostly without conidia, composed of brown walled hyphae (K+ green), intermingled with orange pigment (K+ purplish), hyphae ca. 2–3 µm. *Conidia* 7–15 × 1–1.8 µm, hyaline, non-septate, straight, bacilliform. Thallus K–, C–, KC–, PD+ yellow to orange, UV–. Calcium oxalate not observed. Three secondary metabolites were detected by TLC (solvent B): an unknown metabolite UV+ turquoise, before and after heating ( $R_f$  7), psoromic acid (brown colour,  $R_f$  43) and a third unknown metabolite at  $R_f$  49 with an UV+ greyish-white colour before and after heating.

**Distribution and ecology:**—So far *Arthothelium atrorubrum* is only known from northern Madagascar, and seems restricted to the Marojejy National Park. This corticolous species inhabits rather dense humid montane forests where it might be locally abundant.

**Etymology:**—The epithet *atrorubrum* refers to the blackish colour of the ascomata and the reddish pigment in the hypothecium.

**Remarks:**—In a recent preliminary checklist, 500 lichen species are reported from Madagascar (Aptroot 2016). In this list only two species of *Arthonia*, both foliicolous are mentioned, but not a single species of *Arthothelium* is included.

Several *Arthothelium* species have red coloured ascomata: *A. coccineonigrum* Makhija & Patwardhan (1995b: 207), *A. coccineum* Müller Argoviensis (1893a: 108), *A. gregarinum* (Willey 1887: 53) Zahlbruckner (1903: 91) (= *Coniarthonia gregarina* (Willey) Grube 2001: 496), *A. miltinum* (Krempelhuber 1875: 42 in von Krempelhuber 1875) Müller Argoviensis (1886: 316) and *A. sanguineum* (Nylander 1885: 311) Zahlbruckner (1903: 91) but they have all persistently hyaline and larger ascospores (17–46 µm long) (Nylander 1885; Müller 1886, 1893a; Makhija & Patwardhan 1995b; Grube 2001). *Arthonia erythrogonia* Müller Argoviensis (1893c: 157) described from Costa Rica and also mentioned from Tanzania (Müller 1894a) is similar to the new species by a white thallus speckled with reddish granules, black ascomata with red pigment at the margins, internally with red granules or crystals, but the ascospores are transversally 3–4-septate, 11–13 × 5–6 µm, with two enlarged end cells (Müller 1893a). A study of the type specimen (BR!) revealed that the red pigment in the ascomata reacts K+ purplish, not dissolving, ascospores that are transversally 3-septate, 12–13.5 × 4–4.5 µm. A trentepohlioid photobiont is clearly present.

The new species is also similar to *Arthonia purpurissata* Nylander (1863a: 482) which differs by smaller dark brown globose ascospores (8–9 × 7–8 µm) (Nylander 1863a).

Stizenberger (1891) mentioned the collection of *Arthonia macrotheca* Fée (1837: 42) (= *Arthothelium macrothecum* (Fée) A. Massalongo (1852: 55) by Hildenbrandt from Madagascar during his expedition 1879–1881 (Beentje 1998). This species is characterized by black ascomata without any red pigment (Fée 1837). The type of *A. macrothecum* (G!) from South America has been seen by us but not the material collected in Madagascar by Hildenbrandt. Nevertheless one of us has collected a specimen in Madagascar that agrees well with the type of *A. macrothecum* (D. Ertz 19744), confirming its presence in Madagascar.

**Additional specimens examined:**—MADAGASCAR. Province Diego Suarez: Antsiranana, W of Sambava, Marojejy National Park, along trail from Camp Simpona to summit, rather dense humid montane forest grading into dense sclerophyllous upper montane forests, corticolous, ca. 1500 m, 14°26'19"S, 49°44'29"E, 20 October 2014, D. Ertz 20026 (BR); corticolous, ca. 1600 m, 14°26'27"S, 49°44'23"E, 20 October 2014, D. Ertz 20066 (BR), D. Ertz 20078 (BR); along trail from Camp Marojejia to Camp Simpona, rather dense humid montane forest, ca. 1000 m, 14°26'13.5"S 49°45'19.7"E, 19 October 2014, D. Ertz 19950 (BR).

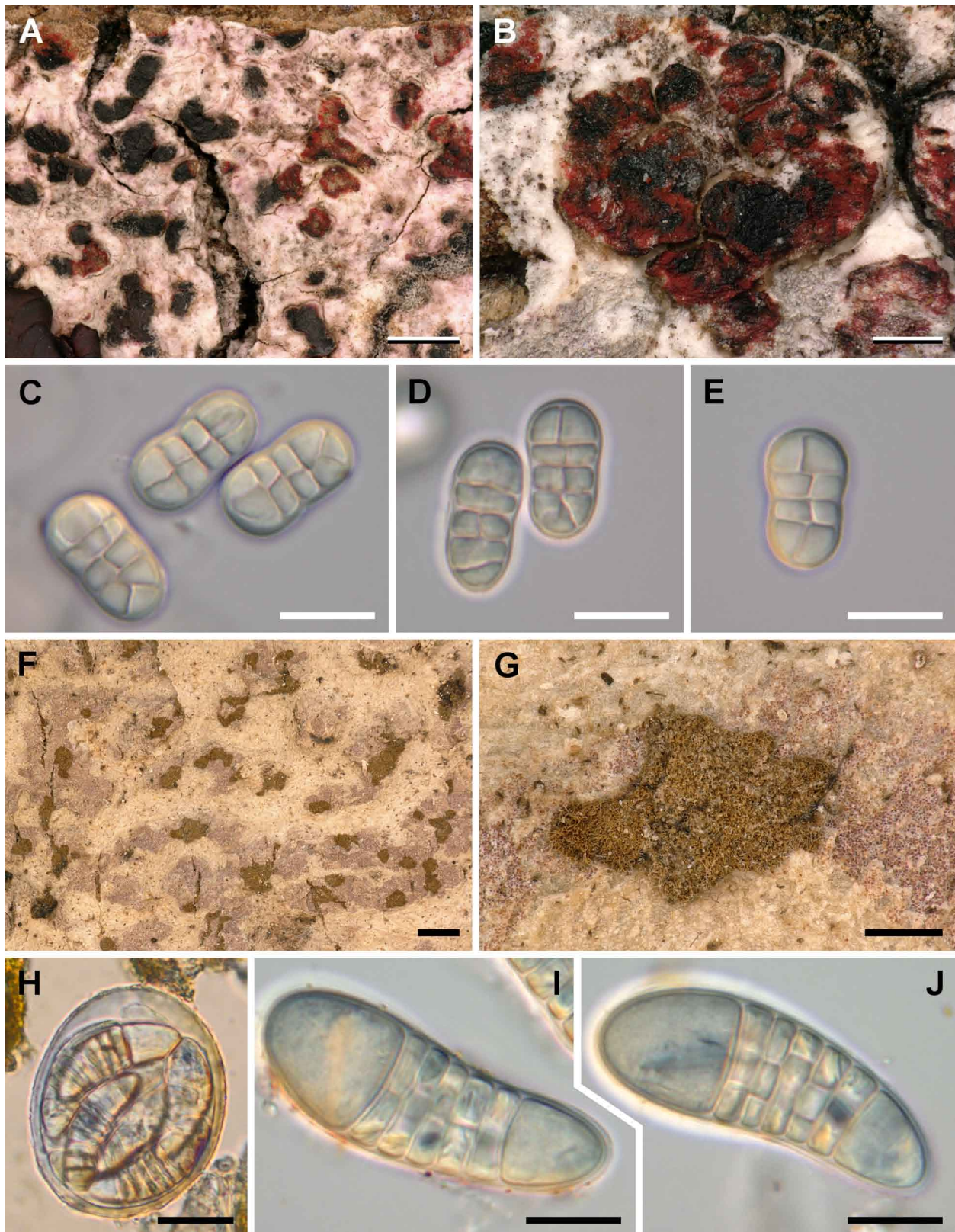
***Arthothelium aurantiacopruinosum*** Van den Broeck & Ertz *sp. nov.* (Fig. 1F–J)

Mycobank 822912

The new species differs from all other *Arthothelium* species by black, orange pruinose ascomata in combination with ascospores of 34–42 × 10–14 µm and having two larger terminal cells.

**Type:**—DEMOCRATIC REPUBLIC OF THE CONGO. Oriental Province: Yangambi, Yangambi Man Biosphere Reserve, mixed tropical rain forest, on the bark of *Scorodophloeus zenkeri*, 400–450 m, 00°46'49.9"N, 24°31'15.9"E, 19 October 2013, D. Van den Broeck 6234 (holotype: BR!).





**FIGURE 1.** New species of *Arthothelium* from Africa. *Arthothelium atrorubrum* (A–E, holotype), *Arthothelium aurantiacopruinosum* (F–J, holotype), A–B, F–G. Thallus with apothecia. C–E, I & J. Ascospores. H. Ascus in water. Scale in A, F = 1000  $\mu\text{m}$ , in B = 500  $\mu\text{m}$ , in C–E, I & J = 10  $\mu\text{m}$ , in G = 250  $\mu\text{m}$ , in H = 20  $\mu\text{m}$ .

*Thallus* corticolous, crustose, inconspicuous to greenish to greyish-green, smooth, continuous. *Prothallus* black. *Photobiont* not observed, doubtfully lichenized. *Ascomata* 0.4–1.0  $\times$  0.25–0.6 mm, numerous, slightly elevated above thallus level, rounded to slightly elongate, occasionally stellate, scattered more or less evenly over the thallus; disc

black, partly or completely covered by orange pruina, K+ purplish, unchanged when wet, fragile, flat to convex, without visible margin. *Excipulum* inconspicuous. *Epihymenium* 30–40 µm thick, with a dark red-brown layer formed by the tips of the interascal hyphae, ca. 2–3.5 µm wide. *Hymenium* 50–80 µm tall, hyaline, interspersed with orange crystals, completely dissolving in K, I+ red, K/I+ blue. *Paraphysoids* hyaline, some with distinct brown caps and walls, branched and netted, ca. 1.8–2.0 µm wide. *Hypothecium* 30–50 µm thick, red-brown, interspersed with orange crystals, completely dissolving in K. *Asci* 50–65 × 45–50 µm (N = 4), globose to ovoid, 8-spored, an ocular chamber not observed, without a K/I+ blue ring structure in the tholus. *Ascospores* 34–42 × 10–14 µm (N = 25), muriform, persistently hyaline, ellipsoid, with two larger terminal cells, rest of the cells divided by 5–7 transversal and 1–2 longitudinal septa; *gelatinous sheet* not observed; spore ontogeny not observed. *Pycnidia* not observed. Thallus K–, C–, KC–, PD–, UV–. Calcium oxalate not observed. TLC (solvent B) revealed an unknown secondary metabolite UV+ greenish before heating (R<sub>f</sub> 10).

**Distribution and ecology:**—The new species is only known from tropical rain forests in the Congo Basin where it grows on bark of trees.

**Etymology:**—The epithet *aurantiacopruinosum* refers to the orange pruina on the ascomata.

**Remarks:**—*Arthothelium spadiceum* Müller Argoviensis (1892: 37) is described as possessing yellow to yellowish or black ascomata but without pruina (Müller 1892). According to the description of Patwardhan & Makhija on the herbarium sheet of the isotype, the ascospores are persistently hyaline without a larger terminal cell and much broader (16–22 µm) than those of the new species (10–14 µm). *A. endoxanthum* Müller Argoviensis (1880: 44) is another species with yellowish-orange, becoming orange-brown, ascomata but they are linear, stellate branched and the ascospores have also no larger terminal cell (Müller 1880; description of Patwardhan & Makhija on the herbarium sheet of the type). Two other species of *Arthothelium* with terminal cells larger at both ends are *A. subilicinum* (Leighton 1869: 181 in Leighton 1871) Zahlbruckner (1922: 136 in Zahlbruckner 1924) and *A. follmannii* C.W. Dodge (1966: 311 in Dodge 1967). *A. subilicinum* differs from *A. aurantiacopruinosum* by much broader (15–20 µm) ascospores and a greenish-brown epihymenium (Makhija & Patwardhan 1995b). *A. follmannii* is characterized by black epruinose ascomata on a thick white thallus and a trentepohlioid photobiont (Dodge 1967).

Several *Arthonia* species like *A. elegans* (Acharius 1810: 135) Almquist (1880: 19)(H!), *A. borbonica* Ertz, Elix & Grube (2010: 222)(BR!), *A. ferruginea* Vainio (1890:165) (M!), *A. karunaratnei* Weerakoon & Aptroot (2016: 133 in Weerakoon *et al.* 2016), *A. ochrocincta* Nylander ex Willey (1890: 8), *A. ochrodes* Nylander ex Willey (1890: 10) (H!), *A. rubiginella* Nylander (1900: 19) (H!) and *A. leucographella* Müller Argoviensis (1888a: 178) have also orange pruinose ascomata but the ascospores have only transversal septa (Almquist 1880; Müller 1888a; Vainio 1890; Willey 1890; Nylander 1900; Ertz *et al.* 2010; Weerakoon *et al.* 2016).

A second specimen with black, orange pruinose ascomata and the same chemistry was found in the Democratic Republic of the Congo in Kisangani, forest reserve of Masako, on a big tree of *Gilbertiodendron dewevrei* (*D. Ertz 14924*, BR). That specimen differs from the new species by ascospores with only one larger terminal cell but the specimen is in poor condition. All the ascospores are more or less degenerated and most of them have a brown colour. It is unclear if this specimen represents a further new species or not.

***Arthothelium frischianum*** Van den Broeck & Ertz *sp. nov.* (Fig 2A–F)

Mycobank 822913

The new species differs from all other corticolous *Arthothelium* species having ascospores with a larger terminal cell by minute (0.2–0.6 × 0.2–0.4 mm) brownish-black ascomata in combination with ascospores of 45–55.5 × 19–24.5 µm and an inconspicuous hypothecium.

**Type:**—MADAGASCAR. Province Diego Suarez: Antsiranana, region Diana, district Diego II, commune Joffreville, Forontany, Morafeu, Parc National de la Montagne d’Ambre, along trail from Gîte des Roussettes to lookout over Cascade Antakarana, through moist, mostly secondary montane forest, from 12°31’37.5”S, 49°10’18.8”E, 1068 m to 12°29’57.3”S 49°10’29.8”E, 880 m, 9 October 2014, *D. Ertz 19511* (holotype: BR!, isotype: TAN).

*Thallus* corticolous, crustose, white to greenish, smooth to slightly rough, following the cracks of the bark, slightly shiny, ca. 50–100 µm thick. *Prothallus* brown. *Photobiont* not observed, doubtfully lichenized. *Ascomata* 0.2–0.6 × 0.2–0.4 mm, minute, sparsely distributed, ± first immersed in the thallus, bursting through it to become sessile, rounded to elongate, not stellate, often covered laterally by a thin layer of thallus, scattered more or less evenly over the thallus; disc brownish-black, not pruinose but often with some remnants of thallus, wet more brownish and partly transparent, rough, without visible margin. *Excipulum* inconspicuous. *Epihymenium* 10–30 µm thick, indistinct, hyphae hyaline to



brown, intermingled with an amorphous brown pigment, slightly darkening in K. *Hymenium* 150–180 µm tall, hyaline to brownish, I+ red, K/I+ deep blue. *Paraphysoids* hyaline, tips without dark caps and walls, sometimes slightly swollen, densely branched and netted, ca. 1.7–2.3 µm wide. *Hypothecium* inconspicuous. *Asci* 85–100 × 70–80 µm (N = 2), globose, 8-spored, with K/I+ blue ring like structure in the tholus. *Ascospores* 45–55.5 × 19–24.5 µm (N = 13), muriform, persistently hyaline, ovoid, with one larger terminal cell, rest of the cells divided by 6–8 transversal and 1–4 longitudinal septa; *gelatinous sheet* not observed; spore ontogeny not observed. *Pycnidia* not observed. Thallus K–, C–, KC–, PD–, UV–. Calcium oxalate not observed. TLC (solvent B): no secondary metabolites observed.

**Distribution and ecology:**—*Arthothelium frischianum* is at present only known from the type location in northern Madagascar.

**Etymology:**—This new species is dedicated to Andreas Frisch for his outstanding work on Arthoniaceae.

**Remarks:**—The new species is similar to *Arthothelium loandense* (Vainio 1901: 447) Zahlbruckner (1922: 128 in Zahlbruckner 1924) that differs by smaller ascospores (35 × 14 µm according to the protologue and 20.5–28.5 × 10–12 µm according to our own observations of the type) (BM!) becoming brown and a K+ olivaceous green reaction of the brown epihymenium. *A. bessale* (Nylander 1873:174) Zahlbruckner (1922: 122 in Zahlbruckner 1924) is also very close but differs by smaller ascospores (10–20 µm broad according to our own observations of the type (M!), 15–16 µm according to the protologue) and much larger ascomata (1–2.2 mm according to our observations, 0.5–0.9 mm fide Nylander 1873). Of the other 18 species with a larger terminal cell: *A. adveniens* (Nylander 1868: 102) Müller Argoviensis (1887a: 76), *A. ampliatum* (C. Knight & Mitten 1860: 106 in Knight & Mitten 1862) Müller Argoviensis (1893b: 61), *A. chiodectoides* (Nylander 1869b: 72) Zahlbruckner (1922:122 in Zahlbruckner 1924), *A. dictyosporum* (Coppins & P. James 1979: 11) Coppins (1989: 210), *A. fuscoroseum* Makhija & Patwardhan (1995b: 211), *A. impolitellum* (Nylander 1867b: 7) Makhija & Patwardhan (1995b: 211), *A. infuscatum* (Krempelhuber 1876: 459 in von Krempelhuber 1876) Müller Argoviensis (1894b: 84), *A. macounii* (G. Merrill 1914: 36) W.J. Noble (1987: 91 in Ahti *et al.* 1987), *A. obtusulum* (Nylander 1888a: 123) Müller Argoviensis (1894b: 84), *A. pellucidum* (C. Knight 1883: 352 in Knight 1883) Müller Argoviensis (1894b: 84), *A. ramosum* Makhija & Patwardhan (1995b: 216), *A. subbessale* (Nylander 1891: 23) Makhija & Patwardhan (1995a: 210) and *A. violaceoatrum* Makhija & Patwardhan (1995b: 220) all have smaller ascospores (12–46 × 3–20 µm) (Nylander 1868, 1869b; von Krempelhuber 1876; Nylander 1888a; Müller 1893b, 1894b; Coppins & James 1979; Ahti *et al.* 1987; Makhija & Patwardhan 1995a, 1995b; Smith *et al.* 2009) while the ascospores of *A. pseudolirellinum* Makhija & Patwardhan (1995b: 215) are distinctly larger (53–70 × 20–22 µm). The ascospores of *A. picilum* A. Massalongo in von Krempelhuber (1871: 867) are ± as broad (20–22 µm) as those of the new species but are distinctly shorter (33–36 µm) (von Krempelhuber 1871). *A. aphanocarpum* (Nylander 1856: 90) Zahlbruckner (1922: 121 in Zahlbruckner 1924) and *A. corticatum* Makhija & Patwardhan (1995b: 208) are characterized by I+ blue ascomatal gel and more or less lirellate larger ascomata (Nylander 1856; Makhija & Patwardhan 1995b). *A. thoraciferum* (Vainio 1921: 297) Zahlbruckner (1922: 137 in Zahlbruckner 1924) differs from the new species by narrower ascospores (10–20 µm broad against 19–24.5 µm in the new species) becoming distinctly dark brown at maturity and larger ascomata (1–1.5 mm) (Makhija & Patwardhan 1995b).

***Arthothelium miesii*** Van den Broeck, Tehler & Ertz *sp. nov.* (Fig.2G–N)

Mycobank 822914

The new species differs from all other *Arthothelium* species by the combination of a thick thallus with immersed, brown to yellowish, stellate to cerebriform, slightly to heavily greyish pruinose ascomata in combination with submuriform, persistently hyaline, ascospores of 16.5–21 × 7–10 µm without larger terminal cells and filiform conidia of 11–21 × 0.5–2 µm.

**Type:**—YEMEN . Socotra: Aden, on top of the Hamaderoh Plateau, on hard dolomitic limestone, 400 m, 12°36' N, 54°17' E, 23 March 1997, *B. Mies 805a* (Herb. No. 14131) (holotype: FR!).

*Thallus* saxicolous or corticolous, crustose, pale cream, sometimes speckled with orange spots of unknown origin and composition, rimose-areolate, cretaceous, up to ca. 1 mm thick, areoles flat to slightly or very convex, very variable, medulla white, filled with many cubic crystals, 1–20 µm wide. *Prothallus* not observed. *Photobiont* cells rounded, ellipsoid to rectangular with greenish content, without orange pigments, trentepohlioid, cells 7.5–16.0 × 6.5–12.0 µm. *Ascomata* up to 2–3 mm diam., numerous, immersed in elevated convex areoles, stellate to cerebriform, with lobes/ramifications of 0.30–1.55 × 0.30–0.70 mm; disc brown to yellowish, of a soft texture, slightly or heavily greyish pruinose, wet ± transparent, sometimes surrounded by whitish thallus tissue. *Excipulum* inconspicuous. *Epithymenium* 25–30 µm thick, hyaline, patchily interspersed with orange crystals, completely dissolving in K. *Hymenium* 55–70 µm tall, I+ blue turning rapidly into orange to red, K/I+ deep blue. *Paraphysoids* hyaline, richly branched and netted, ca.

1.5  $\mu\text{m}$  wide, often with swollen apices and dark caps up to 2.5  $\mu\text{m}$  wide. *Hypothecium* 60–100  $\mu\text{m}$  thick, hyaline, densely interspersed with orange crystals, completely dissolving in K, immediately I+ orange to red, K/I+ deep blue. *Asci* 45–65  $\times$  20–30  $\mu\text{m}$  (N = 5), ovoid, with a distinct stipe, 8-spored, no distinct ocular chamber observed, a K/I+ blue ring like structure in the tholus observed in one ascus. *Ascospores* 14–21  $\times$  7–10  $\mu\text{m}$  (N = 15), submuriform, persistently hyaline, ellipsoid, with 5(–7) transversal and 1 longitudinal septa; *gelatinous sheet* 0.5  $\mu\text{m}$ , not always observed; spore ontogeny macrocephalic, bidirectional. *Pycnidia* abundant, blackish, immersed in pits, rounded, sometimes covered by thallus tissue. *Conidia* hyaline 11–21  $\times$  0.5–2  $\mu\text{m}$  (N = 12), filiform, mostly curved to sickle-shaped, occasionally  $\pm$  straight. Thallus cortex K $\pm$  yellow, C–, KC–, PD+ yellow, UV–, N–; medulla PD+ yellow, K–, N–. Calcium oxalate crystals quadrangular, abundant. One unknown secondary metabolite (UV+ dark violet spot with orange-yellow halo after heating) with  $R_f$  value 43 in B and 52 in C.

**Distribution and ecology:**—*Arthothelium miesii* is only known from Socotra where it has several times been collected on rocks and once on bark.

**Etymology:**—This new species is dedicated to Bruno Mies, the collector of the type specimen, for his effort to investigate the lichen biota of Socotra.

**Remarks:**—In an extensive study of the lichen biota of Socotra, Mies and Schulz (2004) attributed all the saxicolous specimens of *Arthothelium* to the Mediterranean *A. crozalsianum* B. de Lesdain in de Crozals (1924: 112), a synonym of *Arthonia albopulverea* Nylander (1853: 319) according to Sundin (1999), pending a thorough revision of the genera *Arthothelium* and *Arthonia*. According to our observations of the lectotype (H!) this species strongly differs from *A. miesii* by a thin thallus (up to 0.2 mm), doubtfully lichenized, lirellate ascomata, hymenium I+ blue, turning rapidly into red and an olivaceous brown to reddish brown epihymenium.

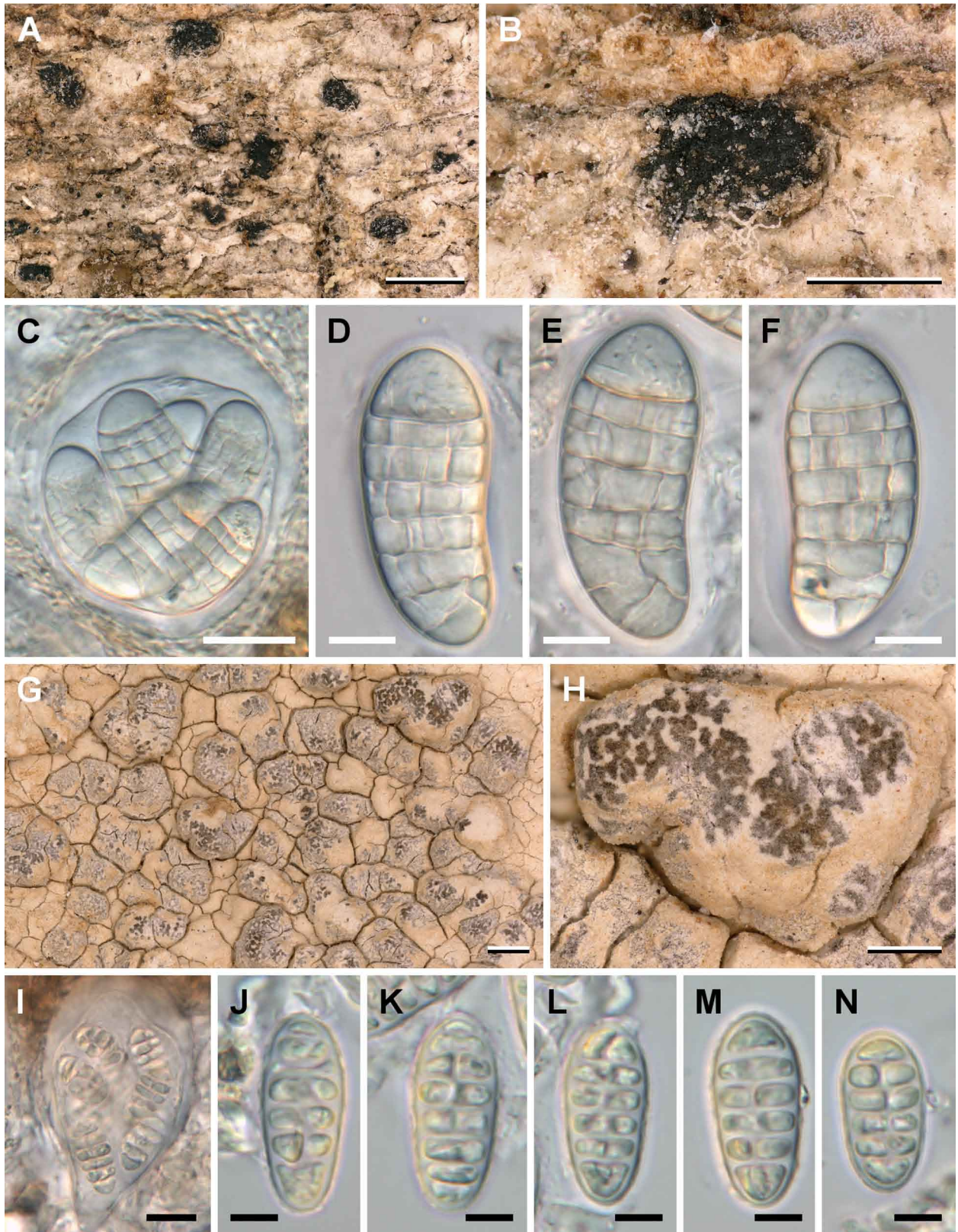
*Arthothelium abnorme* (Acharius 1810: 259) Müller Argoviensis (1880: 287) was also reported from Socotra (Steiner 1902) while two other species were described as new to science. *A. emersum* Müller Argoviensis (1882: 469) was described from material collected in Socotra by Prof. Bayley Balfour and Dr. Schweinfurth while Steiner described *A. variabile* J. Steiner (1902: 101) from the material collected in Socotra and Simha by O. Simony in 1898 and in 1899. According to our observations of the type (BM!), *A. abnorme* differs from the new species by epruinose brown to black ascomata, I+ blue hymenium, a dark brown epihymenium and smaller ascospores (5–8  $\mu\text{m}$  broad instead of 8–10  $\mu\text{m}$ ) and, a different chemistry (according to Makhija & Patwardhan (1995b) no secondary metabolites were revealed by TLC). The lectotype (G!) of *A. emersum* is characterized by simple, rounded to elliptical but never lobate, erumpent brownish black ascomata, I+ blue hymenium, a dark brown epihymenium and a different chemistry, (according to Makhija & Patwardhan (1995b) no secondary metabolites revealed by TLC).

The type of *Arthothelium variabile* (WU!) is present on two branches. On the largest branch two distinct thalli are present. One of them has a whitish thallus with a black prothallus and with brown immersed pycnidia, either solitary or grouped by two, and having a wide open ostiole. The second thallus is inconspicuous, without prothallus and has immersed blackish-brown irregular ascomata with muriform ascospores. No conidia were found on this thallus. Probably the thallus with conidia belongs to another species. In comparison with *A. miesii*, *A. variabile* has epruinose, occasionally with some remnants of thallus, irregular, but not cerebriform, blackish-brown ascomata and larger ascospores (20–32  $\mu\text{m}$  in length).

Seven species of *Arthonia* are mentioned or described from Socotra (Brown & Mies 2012): *A. stictaria* Nylander (1867a: 440) is a lichenicolous fungus (Nylander 1867a). The other six species are lichens with only transversely septate ascospores: *A. applanata* Stizenberger (1891: 198) (= *A. complanatula* Müller Argoviensis 1882: 468), *A. calospora* Müller Argoviensis (1882: 468), *A. cinnabarina* (de Candolle 1805: 323 in de Lamarck & de Candolle 1805) Wallroth (1831: 320) (= *Coniocarpon cinnabarinum*), *A. perpallens* Nylander (1863b: 231), *A. polymorpha* Acharius (1814: 7), *A. speciosa* (Müller Argoviensis 1894a: 286) Grube (2007:58) (Nylander 1863b; Müller 1882, 1887b; Grube 2007).

At present ten *Arthothelium* species with a saxicolous habitat are known. Morphologically, chemically and anatomically the new species is most similar to *A. desertorum*, a species known from Namibia and Galapagos (Aptroot & Wirth (2006). According to these authors this species contains divaricatic acid. TLC performed by us on *A. miesii* (solvents B and C) revealed the presence of one unknown secondary metabolite (UV+ dark violet spot with orange-yellow halo after heating) with  $R_f$  value 43 in B and 52 in C, far below that of divaricatic acid ( $R_f$  53 in B and  $R_f$  67 in C) and just above that of psoromic acid in B ( $R_f$  40). The same secondary metabolite (thus not divaricatic acid) and calcium oxalate has been found by us in *A. desertorum* that differs from *A. miesii* by ascomata never becoming distinctly cerebriform, hymenium I+ blue, bacilliform, straight to slightly curved conidia, ascospores with 1–2 longitudinal and 4–5 transversal septa, becoming brown (dark brown when overmature). The size of the conidia in the protologue of *A. desertorum* is 6–8  $\times$  0.8–1.0  $\mu\text{m}$  according to Aptroot & Wirth (2006) whilst we observed conidia of 4.0–5.6  $\times$  0.9–1.6  $\mu\text{m}$ . Contrary to the protologue, ascospores with more than two longitudinal septa were not observed (N = 20). The picture in the protologue shows also not more than two longitudinal septa in the ascospores.





**FIGURE 2.** New species of *Arthothelium* from Africa and Socotra. *Arthothelium frischianum* (A–F, holotype), *Arthothelium miesii* (G–N, holotype). A–B, G–H. Thallus with apothecia. C, I. Ascus in water. D–F, J–N. Ascospores. Scale in A, G = 1000  $\mu\text{m}$ , in B, H = 500  $\mu\text{m}$ , in C = 25  $\mu\text{m}$ , in D–F, I = 10  $\mu\text{m}$ , in J–N = 5  $\mu\text{m}$ .

The ascospores of *Arthothelium feuereri* Aptroot & Seaward (2004: 119 in Seaward & Aptroot 2004) are characterized by a larger terminal cell and are much larger (40–50  $\times$  20–25  $\mu\text{m}$ ) (Seaward & Aptroot 2004). *Allarthothelium elliotti* (Vainio 1896: 263) Zahlbruckner (1907: 241), *Arthothelium diffluens* (Nylander 1888b: 17)



Imshaug & Fryday (2002: 422 in Fryday 2002), *A. evanescens* Øvstedal (2001: 554 in Øvstedal & Gremmen 2001) and *A. halophilum* Follmann (1968: 373) have also much larger ascospores (exceeding 20 µm in length) (Vainio 1896; Follmann 1968; Øvstedal & Gremmen 2001; Fryday 2002). The other four saxicolous species, *A. galapagoense* Huneck & Follmann (1969: 169), *A. pacificum* Follmann (1968: 375), *A. spilomatoides* (Nylander 1855: 169) Zahlbruckner (1922: 135) in Zahlbruckner 1924) and *A. saxicolum* Makhija & Patwardhan (1997: 169), have a different chemistry and an hymenium that reacts I+ blue (Nylander 1855; Follmann 1968; Huneck & Follmann 1969; Makhija & Patwardhan 1997).

*Arthothelium chilense* C.W. Dodge (1966: 311 in Dodge 1967) and *Mycarothelium angustissimum* Vainio (1930: 169 in Vainio 1929–1930), both with persistently hyaline ascospores of 18–21 × 6–10 µm differ from the new species by a dark brown epihymenium and 1–2 longitudinal septa. Moreover *A. chilense* has round to oblong ascomata and in *M. angustissimum* the photobiont is absent (Vainio 1929–1930; Dodge 1967).

**Additional specimens examined:**—YEMEN. Socotra: Sefflah, the ridge just S of the village on S coast at the E most part of the island, on limestone, 400–600 m, 12°30.723'N, 54°26.037'E, 24 March 2008, *A. Tehler 9345* (S); in the southern part of the island along the road where it leads up into the mountains from the south, saxicolous, 300 m, 12°23.115'N 53°55.628'E., 23 March 2008, *A. Tehler 9328* (S); corticolous, *A. Tehler 9330* (S); Homill, in the eastern part of the island, on the ridge facing the sea E, saxicolous, 400–450 m, 12°35.472'N 54°18.693'E, 22 March 2008, *A. Tehler 9321* (S).

### Key to the species of *Arthothelium* (*Mycarothelium* included) reported from tropical Africa and Socotra

The key is based on the protologues, information on JSTOR (<http://plants.jstor.org>), other literature (e.g. Willey 1890; Makhija & Patwardhan 1995a, 1995b; Sundin 1999; Grube 2007; Smith *et al.* 2009) as well as on the study of the following type species: *Arthothelium abnorme* (BM!), *Arthonia albopulvurea* (H!), *Arthothelium aurantiacum* Müller Argoviensis (1890: 345) (G!), *A. beccarianum* Baglietto (1875: 252) (M!), *A. consanguineum* Müller Argoviensis (1888b: 207) (G!), *A. desertorum* (KR!, STU!), *A. distentum* (Vainio 1901: 446) Zahlbruckner (1922: 125 in Zahlbruckner 1924) (BM!, TUR!), *A. emersum* (G!), *A. homoeophanum* (Nylander 1863b: 236) Zahlbruckner (1922: 126 in Zahlbruckner 1924) (H!), *A. loandense* (BM!), *A. macrothecum* (G!), *A. variabile* (WU!), *Mycarothelium angustissimum* (TUR!) and *M. limae* Vainio (1930: 169 in Vainio 1929–1930) (TUR!). According to the protologue, the hymenium of *A. distentum* reacts I+ blue while that of *A. macrothecum* is I+ red. A study of the type of *A. distentum* present in BM (the type of TUR is an oligotype, so we did not perform a destructive analysis) revealed an hymenium I+ blue but turning into red. *A. distentum* is similar in all other aspects to *A. macrothecum* and has therefore been reduced in synonymy with the later. Makhija & Patwardhan (1995a) considered *A. consanguineum* to be conspecific with *A. emersum* but we prefer to keep them as different species because their types specimens appears too different.

1. Hypothecium or ascomata red ..... 2.
- Hypothecium or ascomata not red ..... 3.
2. Ascomata black; hypothecium with red pigment, K+ purplish; hymenium I+ red; ascospores not exceeding 20 µm in length, becoming dark brown ..... *Arthothelium atrorubrum*
- Ascomata red; hypothecium without red pigment; red pigment in epihymenium K+ pale brown; hymenium I+ blue; ascospores exceeding 20 µm in length, persistently hyaline ..... *Arthothelium sanguineum*
3. Ascomata orange pruinose, K+ purplish ..... *Arthothelium aurantiacopruinosum*
- Ascomata not orange pruinose, K- ..... 4.
4. Thallus orange ..... *Arthothelium aurantiacum*
- Thallus not orange ..... 5.
5. Ascospores with one or two larger terminal cells ..... 6.
- Ascospores without larger terminal cell(s) ..... 10.
6. Ascospores with two larger terminal cells ..... *Arthothelium feuereri*
- Ascospores with one larger terminal cell ..... 7.
7. Ascospores not exceeding 30 (–35) µm in length ..... *Arthothelium loandense*
- Ascospores exceeding 30 (–35) µm in length ..... 8.
8. Ascomata irregular to very much elongate; hymenium I+ blue ..... *Arthothelium corticatum*
- Ascomata rounded to slightly elongate; hymenium I+ red ..... 9.
9. Thallus white to greenish; ascomata brownish-black; epihymenium brown; ascospores transversely 6–8-septate, 19–24.5 µm broad ..... *Arthothelium frischanium*
- Thallus whitish grey to grey; ascomata black; epihymenium olive-green; ascospores transversely 7–11-septate, 9.9–20 µm broad ..... *Arthothelium bessale*
10. Ascospores not exceeding 30 (–35) µm in length ..... 11.
- Ascospores exceeding 30 (–35) µm in length ..... 18.

11.	Hymenium I+ persistently blue .....	12.
-	Hymenium I+ blue, turning rapidly into red .....	14.
12.	Ascomata distinctly grey-pruinose .....	<i>Arthothelium desertorum</i>
12.	Ascomata epruinose, with or without remnants of thallus .....	13.
13.	Ascomata with or without remnants of thallus, irregularly rounded to short lirelliform; asci with KI+ blue ring like structure in the tholus; ascospores hyaline but becoming brown, 14–24 × 7–12 μm .....	<i>Arthothelium beccarianum</i>
-	Ascomata without remnants of thallus, lirellate; asci without blue ring like structure in the tholus; ascospores hyaline (over aged spores slightly brownish), 14–19 × 5.5–8 μm .....	<i>Arthothelium consanguineum</i>
14.	Ascomata rounded to elliptical, strongly emergent to almost adnate .....	<i>Arthothelium emersum</i>
-	Ascomata lirellate, stellate, branched or cerebriform, immersed to erumpent .....	15.
15.	Ascomata brown to yellowish, greyish pruinose, stellate to cerebriform .....	<i>Arthothelium miesii</i>
15.	Ascomata dark brown to black .....	16.
16.	Ascomata immersed; ascospores 20–32 μm, becoming brown and ornamented with brown dots .....	<i>Arthothelium variabile</i>
16.	Ascomata immersed to semisessile; ascospores 9–21.5 μm, persistently hyaline .....	17.
17.	Ascospores with (6–)7 transversal and 1–2 longitudinal septa; asci without blue ring like structure in the tholus .....	<i>Mycarthothelium angustissimum</i>
-	Ascospores with 3–5 transversal and 0–1 longitudinal septa; asci with KI+ blue ring like structure in the tholus .....	<i>Arthonia albopulvurea</i> (= <i>Arthothelium crozalsianum</i> )
18.	Epihymenium K+ violet; asci without blue ring like structure in the tholus .....	<i>Arthothelium homoeophanum</i>
-	Epihymenium K– or K+ olivaceous; asci with KI+ blue ring like structure in the tholus .....	19.
19.	Lichenized; ascomata 0.5–1.5 × 0.5–0.75 mm; epihymenium K+ olivaceous; ascospores hyaline becoming brown .....	<i>Arthothelium macrothecum</i>
-	Not lichenized; ascomata 0.2–0.7 × 0.2–0.5 mm; epihymenium K–; ascospores persistently hyaline .....	<i>Mycarthothelium limae</i>

## Discussion

The reduction of ascomatal borders characteristic of the family Arthoniaceae (Frisch *et al.* 2014) is clearly present in the four new species. *Cryptothecia* Stirton (1876: 164) is another genus of Arthoniaceae with muriform ascospores but this genus does not form ascomatal structures, the asci being loosely scattered in ascigerous areas of the thallus (Jagadeesh Ram & Sinha 2016). The genus *Helminthocarpon* Fée (1837: 156), recently placed in the family Arthoniaceae (Aptroot 1999), has also muriform ascospores but differs by lirellate ascomata resembling species of Graphidaceae and a distinct carbonized excipulum that is deeply buried below a thick thalline layer (Bungartz *et al.* 2013). Sparrius (2009) described the genus *Synarthothelium* Sparrius (2009: 374) to accommodate species with a thalline exciple and pluricarpocentral (syn)ascomata, contrary to our new species.

Two of the new species are characterized by red/orange pigments. Such pigments have been reported from different genera in *Arthonia/Arthothelium* s.lat. (Grube 2001; Sundin *et al.* 2012; Menezes *et al.* 2013; Frisch *et al.* 2014). *Coniarthonia* Grube (2001: 492) is characterized by the presence of large amounts of red or orange pigments but those pigments are always visible from the outside and not in the hypothecium as is the case with *A. atrorubrum*. In contrast to *A. atrorubrum* and to *A. aurantiacopruinosum*, the ascomata in *Coniarthonia* are also more or less poorly delimited. In *Coniocarpon* de Candolle (1805: 323 in de Lamarck & de Candolle 1805) the pigments are also visible on the outside of the ascomata as is the case with *A. aurantiacopruinosum* but at present only species with red and/or white pruina are included in *Coniocarpon* (Frisch *et al.* 2014). To decide if species with orange pruina are genetically related to *Coniocarpon* molecular studies are needed.

From the description of the four new species it is clear that they do not form a monophyletic group. They may later on be included in a larger monophyletic group together with a number of other species. The shape of the ascomata is very variable which is minute in *Arthothelium frischianum*, stellate to cerebriform in *A. miesii* and irregularly rounded in *A. atrorubrum* and *A. aurantiacopruinosum*. Presence or absence of pruina, presence or absence of coloured pigments and the colour of the ascomata are also very variable. The same holds true for the ascospores which are submuriform in *A. atrorubrum* and *A. miesii* and muriform in the other species. *A. aurantiacopruinosum* is characterized by ascospores with two larger terminal cells and those of *A. frischianum* have one larger terminal cell. The chemistry is also very different in all the four species. None of the new species seems very close to the type species, *A. spectabile*, which has black, ± rounded, epruinose ascomata, and the ascospores have no larger terminal cells and are muriform (not submuriform). In the past several classifications have been made on morphological grounds: photobiont (Vainio 1896, 1928), colour of ascomata (Zahlbruckner 1903), presence or absence of a larger terminal cell (Makhija & Patwardhan 1995b) or other characteristics (Sundin & Tehler 1998), but they probably do not reflect evolutionary patterns. Therefore we have refrained to attribute the species to one of those classifications, pending a molecular revision of the genus.



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