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The diatom collection of Albert Grunow (1826–1914) at the herbarium of the Natural History Museum Vienna (W)

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Abstract

Albert Grunow (1826–1914) was a prolific diatomist, who described thousands of taxa. His work is foundational and greatly improved our knowledge of diatom taxonomy. Grunow's historical collection is still relevant for modern biodiversity research, as it includes many types and other historical material. Thorough taxonomic work considering type and other relevant original material is critical in view of the role of diatoms as aquatic bio-indicator species (e. g. for water quality monitoring purposes), Earth's history, and environmental change modelling.

Here, we introduce the Grunow diatom collection at the Department of Botany of the Natural History Museum Vienna (herbarium W), its components and included object types, their organisation and management. The collection is complex for various reasons. For one, it encompasses a great variety of material types (e. g. loose diatomaceous earth in capsules; samples mounted on card, glass, or mica; microscope slides and other preparations; drawings; accession books (= catalogue); literature annotated by Grunow). Second, its components are interlinked and need to be considered together for identifying and locating specimens, which therefore involves a series of steps. Third, Grunow's collection includes a lot of material sent to him by other collectors, resulting in various numbering systems for collector vs sample numbers that need to be reconciled, often across multiple institutions. The aim of this paper is to detail this complexity for facilitating material requests to the W herbarium by giving a step by step example pinpointing original and other historical material of *Achnanthes inflata* (Kützing) Grunow. This shows how such material is located in the collection, so requesters know which information to supply to speed up a search within the diatom collection.

Key words: Bacillariophyta, cryptogams, curation, de Toni, SMS Novara expedition, Henri Van Heurck, George A. Walker Arnott.

Zusammenfassung

Albert Grunow (1826–1914) war ein ausgesprochen produktiver Diatomeenforscher, der tausende Taxa beschrieben hat. Seine grundlegende Arbeit hat unser Wissen zur Kieselalgentaxonomie enorm vorangetrieben. Grunow's historische Sammlung ist nach wie vor relevant für moderne Biodiversitätsforschung, da sie viele Typen und weiteres historisches Material enthält. Gründliche taxonomische Studien unter Einbeziehung von Typen und weiterem relevanten Originalmaterial ist essentiell in Anbetracht der Rolle von Kieselalgen als Bioindikatoren in aquatischen Ökosystemen (zum Beispiel für Wasserqualitätskontrollen), Erdgeschichte und Klimawandelmodellierung.

In diesem Beitrag stellen wir die Grunow Diatomeensammlung in der Botanischen Abteilung des Naturhistorischen Museums Wien (Herbarium W) vor, seine Bestandteile und die enthaltenen Objekttypen, deren Organisation und Management. Die Sammlung ist aus verschiedenen Gründen komplex. Zum einen,

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beinhaltet sie eine große Vielfalt von Materialtypen wie losen Kieselgur in Kapseln; Proben die auf Papier, Glas oder Mica präpariert sind; Objektträger und andere Präparationen; Zeichnungen; Zugangsbücher (= Katalog); Bücher mit Anmerkungen von Grunow. Zum anderen, sind diese Bestandteile miteinander verbunden und müssen zusammen in Betracht gezogen werden um bestimmte Proben zu identifizieren und zu finden, was eine Serie von Schritten beinhaltet. Des Weiteren, enthält die Grunowsche Sammlung viel Material das ihm durch andere Sammler zukam, mit dem Ergebnis, dass eine Reihe von Nummerierungssystemen wie Sammelnummer vs Probennummer, oft über mehrere Institutionen hinweg, entwirrt werden müssen. Das Ziel dieses Beitrags ist diese Komplexität aufzuzeigen um Materialanfragen an Herbarium W zu vereinfachen. Wir tun dies anhand eines Beispiels wo wir Schritt für Schritt Original- und anderes historisches Material von *Achnanthes inflata* (Kützing) Grunow orten. Dies zeigt wie Material in der Sammlung aufgefunden wird damit Anfragende wissen, welche Informationen angegeben werden sollen um die Suche in der Sammlung zu beschleunigen.

Introduction

Albert Grunow (1826–1914) was an extremely productive phycologist with a focus on diatoms. Interrogating DiatomBase (Kociolek et al. 2021) returns ca 3,000 hits for diatom taxon names attributed to Grunow. Most of his samples, including the relevant type and ancillary material for these descriptions, are archived at W (herbarium acronyms follow Index Herbariorum, http://sweetgum.nybg.org/science/ih/; see Thiers 2021). Herbarium BR (Meise Botanic Garden, Belgium) also holds a substantial amount of Grunow material in the form of duplicate slides, illustrations used for descriptions in Van Heurck (1880–1885), but also original material no longer available at W for various reasons. This is because Grunow collaborated closely with Henri Van Heurck (1838–1909) on "Synopsis des Diatomées de Belgique, Atlas" (1880–1885) and the accompanying "Types du Synopsis des Diatomées de Belgique" (1882–1885); Van Heurck's sample and slide collection including Grunow material is kept at BR.

A prime, basic aspect of biodiversity research is taxonomy and the accurate application of names. Even baseline knowledge about biodiversity is valuable, but diatom taxonomy also has a bearing on applied research. Bacillariophyta are relevant for our understanding of Earth's (recent) history and environmental monitoring. This is because diatoms have specific ecological preferences for a broad array of parameters such as pH, nutrients, and salinity. Many species are restricted in their distributions (Vyverman et al. 2007, Vanormelingen et al. 2008, Kociolek et al. 2017, Kociolek 2018, Verleyen et al. 2021). Knowledge about these environmental preferences are crucial for using diatoms as aquatic bio-indicators for water quality in freshwater, soil and marine ecosystems. Due to their highly resistant silica (= glass) cell walls that can last for millions of years, diatoms are also indicator species of another kind, as they tell us about Earth's geological history. The presence of certain species in lake and ocean sediments allows for the reconstruction of previous environmental conditions in those localities. In addition, diatomaceous earths are mined for commercial uses, such as stabilisers (e. g. dynamite), filters (e. g. in brewery), and drying agents (e. g. insect pest management). A thorough understanding of diatom taxonomy is the basis for meaningful environmental analyses. Through his many carefully documented species descriptions, particularly drawings, Grunow's work underpins an important part of the relevant taxonomy for modern diatom research. Building upon his work with methods that allow for more detailed morphological study, such as scanning electron microscopy (SEM), has led to the resolution of taxonomic problems and a more refined use of these names in applied research.

The main goal for this contribution is to facilitate external requests for material from the Grunow diatom collection at the Department of Botany (herbarium W) of the Natural History Museum Vienna (the latter abbreviated NHMW hereafter). The collection is complex due to its many interlinked parts, which need to be considered together in order to identify relevant (type) material. The collection comprises several different object types linked through various numbering systems and a catalogue (also called 'accession books' herein and elsewhere). It is therefore useful to give some background on the collection, its organisation, the man who amassed it, with whom he collaborated, and the literature he used in order to track specimens at W more easily.

Biographic sketch for Albert Grunow (3.XI.1826–17.III.1914)

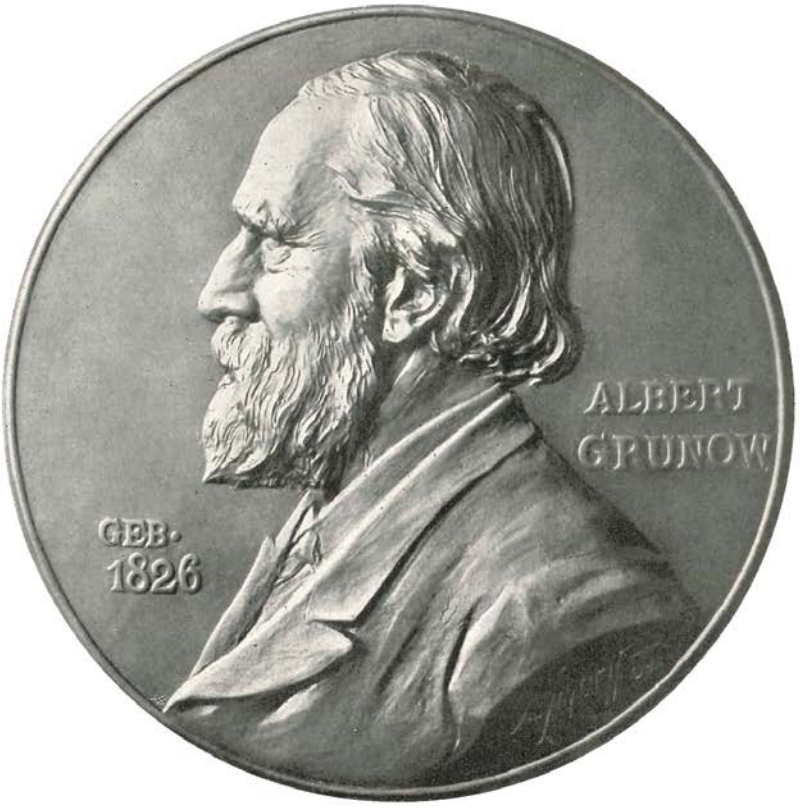
The following information is mainly derived from RECHINGER (1915), who stated that he got most of it from one of Grunow's two daughters, Albertine von Escher. Grunow was a so-called lay botanist and had a full-time role as chemist at the Krupp and Schoeller Metalworks in Berndorf, Lower Austria (1851 until retirement in 1901). In view of this, his scientific output is all the more exceptional; apparently, he used any available free time for research on algae, and in particular diatoms. Grunow was an astute, thorough, meticulous, and very hard-working scientist. As a person, he was gregarious and liked the arts; he was an excellent draughtsman and painter, wrote poems, made music (piano, zither, singing) and also enjoyed mountaineering.

Albert Grunow (Fig. 1) was born on the 3rd of Nov. 1826 in Berlin, Germany. At University he studied Chemistry, Greek, Hebrew, and Latin. Later he also learnt English, French, Hungarian, Italian, and Spanish. His passion was for natural history; as a school boy he made insect and mineral collections. The astronomer S.H. Schwabe (1789–1875) was an early mentor, and through his connections Grunow was given Princess Frederica of Prussia's (1796–1850) diatom collection. Aside from algae, Grunow also collected lichens, liverworts, mosses, and a few angiosperms, which he eventually donated to W.

In 1885, Grunow did a world tour and collected algae and particularly diatoms in the following localities: Alexandria and Suez (Egypt); Colombo (Sri Lanka); Glenelg and Sydney (Australia); Auckland (New Zealand); New Caledonia; and Honolulu (HI), Santa Cruz (CA), New Haven (CT), and Nahant (MA) in North America. Grunow also visited Japan (MAYERHOFER 1901), but it is unclear whether this was during his world tour. During the last years of his life, he was no longer able to pursue diatom research, in particular microscopy, due to his deteriorating eyesight. Grunow passed away on the 17th of March 1914 and left a rich legacy for subsequent diatomists. Grunow's many descriptions are foundational, and his specimens are crucial for the development of diatom taxonomy.

A short introduction to diatoms (Bacillariophyta)

As microscopically small organisms, diatoms are not the most obvious collection objects one expects to encounter in herbaria, and few biologists learn about them during their training. A brief introduction to these organisms may therefore be helpful here for the non-specialist.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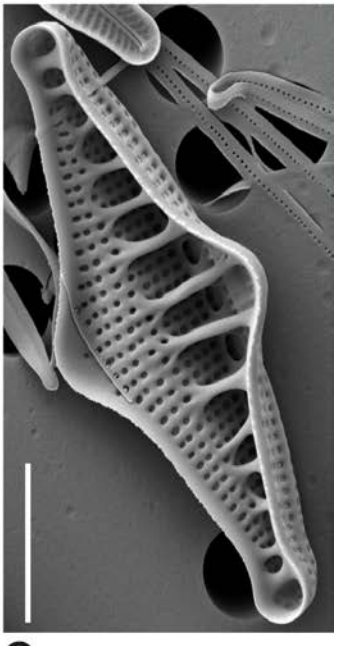

C

Diatoms (Bacillariophyta) are a member of the Ochrophyta, a group of predominantly photosynthetic organisms within the heterokonts or stramenopiles (KEELING 2004, DERELLE et al. 2016). Ochrophyta are currently understood to be composed of two subgroups, Khakista and Phaeista, the former composed of diatoms plus Bolidophyceae. The latter are a species-poor group of picophytoplankton with no more than ca 20 included species (ICHINOMIYA et al. 2016).

Heterokonts are defined by the possession of mastigonemes (hairs on the flagellum) with a unique tripartite structure. Many diatom groups have lost the characteristic external flagella found in most other stramenopiles. The Coscinodiscophyceae (the 'radial centric' diatoms) and most of the Mediophycaeae (the 'polar centric' diatoms) retain male flagellated gametes, while the more derived pennate diatoms (Bacillariophyceae) exhibit morphological isogamy and physiological anisogamy. Nevertheless, diatoms still code for the proteins unique to these hairs (BLACKMAN et al. 2011). Diatoms have chlorophyll (a and c, but not b, and fucoxanthin) and are photosynthesising autotrophs.

Estimates of the numbers of diatom species range from 20,000 to 2 million; perhaps a more reasonable estimate is around the 100,000 mark (MANN & VANORMELINGEN 2013), although the usefulness of such numbers may be questionable (WILLIAMS 2020). In many cases, monophyly has yet to be demonstrated at all ranks including genera, families, orders, etc.

The age of origin for diatoms has not been established with any certainty. Estimates from molecular data (MEDLIN 2011, NAKOV et al. 2018, between 250 and 190 mya, Jurassic) and morphology (HARWOOD et al. 2007, around the Cretaceous) differ. With respect to fossil evidence, the oldest specimens definitively identified as diatoms are found in a number of Cretaceous deposits (e. g. HARWOOD et al. 2007, WITKOWSKI et al. 2011, ca 65 mya), but more recently specimens of an unidentified species of *Hemiaulus* HEIBERG were found in Late Jurassic Thai Amber (GIRARD et al. 2020).

In terms of morphology, diatoms uniquely produce silica cell walls. These glass "shells" (called frustules) are composed of two parts (valves) that fit together like a box of chocolates with one valve larger than the other. They have distinctive shapes, ornamentations (e. g. spines), and perforations (areolae). These morphological characters including valve outline and dimensions, arrangement patterns of spines and areolae, and presence/absence of a raphe (central slit(s)) are used for species identification.

Diatoms usually prefer aquatic to mesic conditions and live in freshwater, brackish or marine environments, but are also found in and on soil and growing epiphytically on macroalgae, lichens, and land plants, such as mosses and liverworts. As primary producers, they generate more than 20 % of the oxygen heterotrophs breathe (SCARSINI et al. 2019) and are a major player in global carbon cycling. Diatoms are an important building

◀ Fig. 1: (A) Portrait of Albert Grunow (1826–1914) from a medallion commemorating his 40th work anniversary at Krupp and Schoeller Metalworks in Berndorf, Lower Austria; (B) sample with Grunow's first diatom collection number; (C) scanning electron micrograph showing the internal view of a valve of *Grunowia tabellaria* (GRUNOW) RABENHORST named to honour Grunow. The scale bar represents 5 µm. Image credit: Carlos E. Wetzel, Environmental Research & Innovation (ERIN) Department, Luxembourg Institute of Science and Technology (LIST), Belvaux, Luxembourg.

block in the food web, as they form the basic energy source for many marine and freshwater organisms, such as plankton feeders and aquatic insects. Hence, the ecological importance of diatoms cannot be underestimated.

Diatoms in herbaria

Research vouchers of diatoms and large collections made by various (historical) diatomists are often, but not always, archived in herbaria and museums, though such specimen collections are relatively rare in botanical departments. As the samples differ from conventional pressed and dried specimens mounted on card, they require special consideration regarding collection management, with each of the differing preparation types needing different storage systems. Preparation types (Figs 2 & 3) include loose diatomaceous earth in packets or other receptacles (from pillboxes to glass vials and larger heavy bottles), (cleaned) material dried onto pieces of glass and under mica affixed with gummed linen strips, diatoms on macroalgae or other substrates mounted on card, microscope slides, SEM stubs, and cleaned preparations in liquid. All require different storage units, such as stub storage boxes in desiccators for SEM stubs to keep them dry, or appropriately sized boxes for stacks of pop-up slide holders. Microscope slides should be stored horizontally in pop-up slide holders, because (historical) cover slip mounting media, such as Hyrax, Styrax or Naphrax, remain in flux, even if at a slow rate, and vertical storage causes faster deterioration. Capsules may be best stored "index card style", i. e. upright in boxes to prevent finely ground diatomaceous powder from leaking out of envelopes, but can also be stored horizontally with multiple packets per folder in herbarium boxes.

Digitisation of these various object types requires different approaches for each (to be covered in a future paper). As the specimens are microscopically small, conventional high-resolution images of the samples are not particularly useful, other than conveying what the preparation type is and displaying unique identifiers, such as bar or QR codes, and label data. The specimens themselves are best represented with light and/or scanning electron micrographs, but this requires specialists generating these for specific research projects, which mostly goes beyond collection curation and management. However, online sharing of ancillary metadata such as catalogues for particular collections is valuable, because some important collections that include many types and are the basis for taxonomic decisions are represented partially in several different herbaria (see next section for an example). Digitisation effort does therefore not have to be duplicated and researchers have a better idea where samples are available.

Fig. 2: Different preparation types of samples in the Grunow collection: loose diatomaceous earth in various receptacles such as (A) packets, as for Grunow sample 793 from Miocene rocks from Nancoori [Nancowry Island, Nicobar Islands]; (B) glass vials as seen for Grunow sample 2117 collected in Maasø [Måsøya], Finnmark, Norway; (C) larger bottles containing chunks of rock; (D) Grunow kept some of his fossil diatom samples in pillboxes. Note Grunow sample 788 of edible soil purchased at a market in Bogor, Indonesia (Java) and collected during the SMS Novara expedition (blue arrowhead), though not by him; Note that no stable identifiers currently in use at W (QR codes) are shown due to image cropping and that any acquisition numbers seen are obsolete as accession numbers and should not be used in future publications (2A, blue arrowhead). ▶


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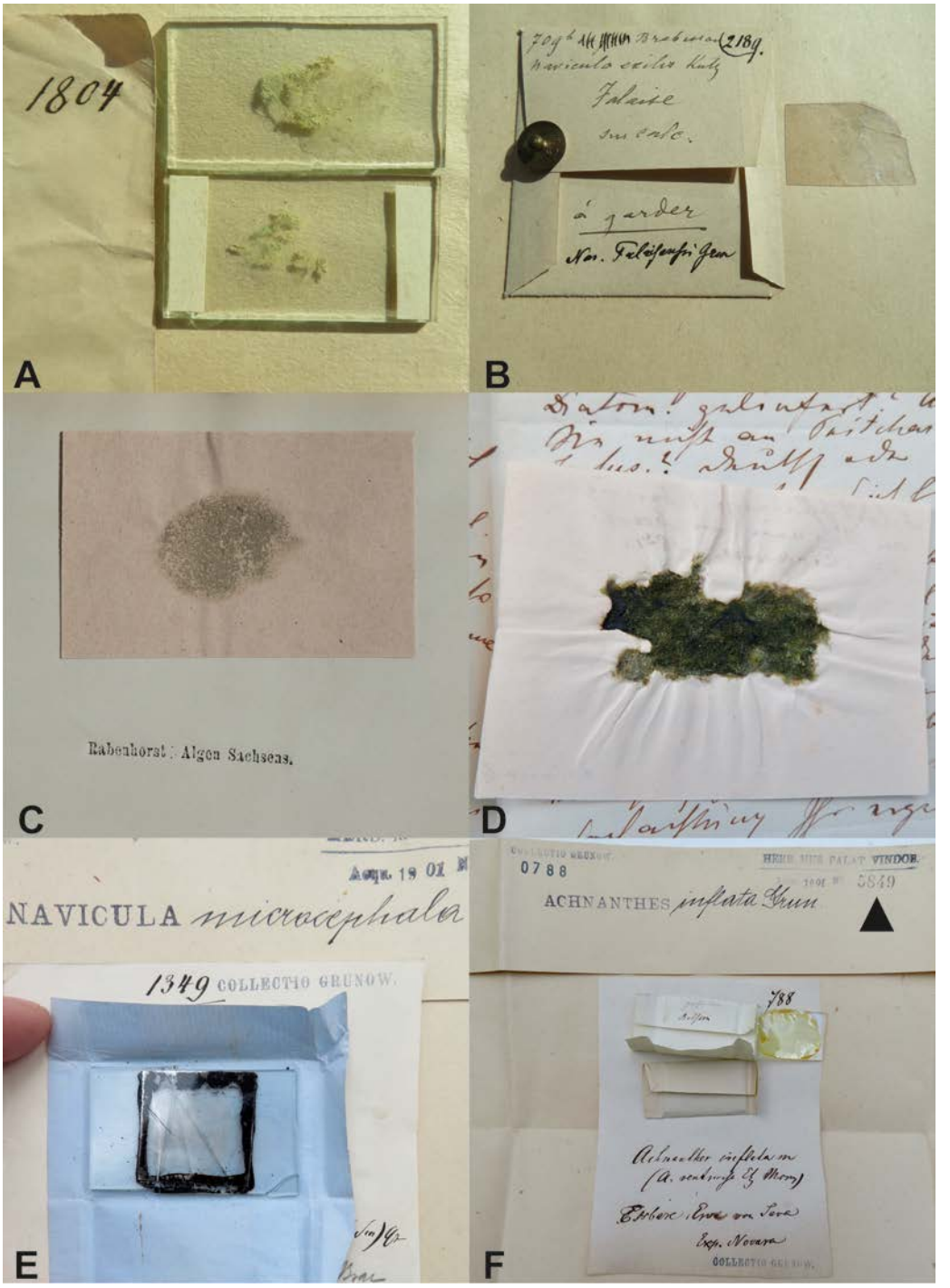
1804
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Rabenhorst: Algen Sachsens.
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NAVICULA microcephala
1349 COLLECTIO GRUNOW.
E
0788
ACHNANTHES inflata Grun
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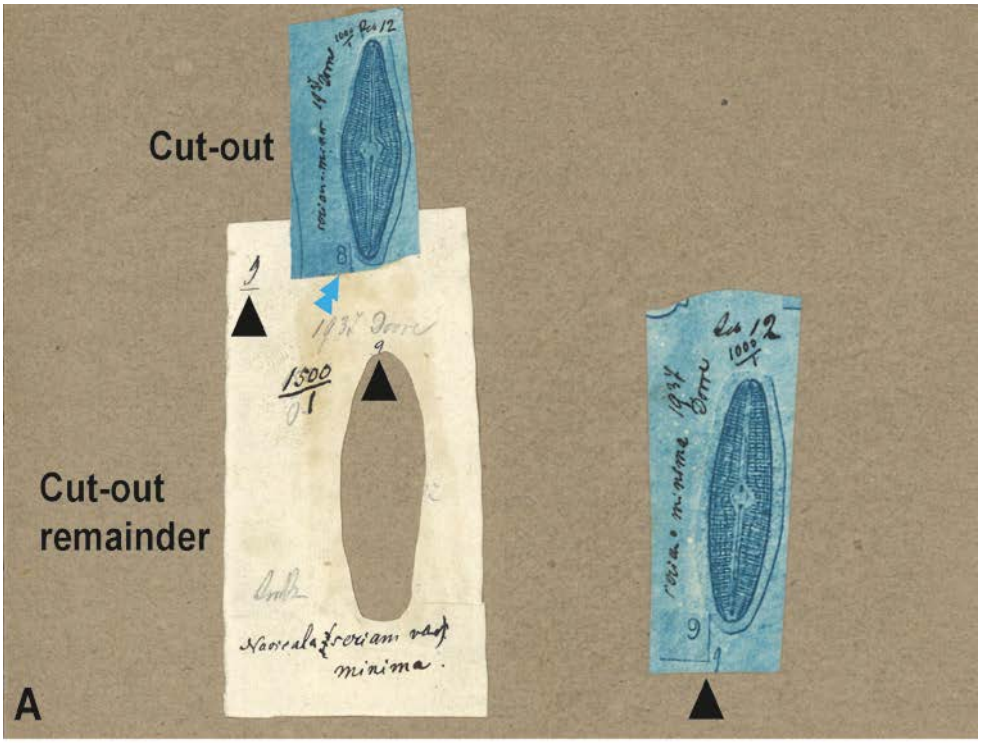
F

The diverse and fragmentary nature of historical diatom collections as evidenced by Grunow's collection at W

Many 19th century diatomists collaborated extensively and exchanged their material, which was later conserved in herbaria and collections worldwide. As a result, original material of several foundational diatomists is dispersed all over the world, rather than being kept as a single collection in one institution. Grunow's collection at W is a prime example for the dispersed nature of historical diatom collections as it includes samples from several other naturalists (see below). Many other diatom collections have been similarly assembled. For example, the Ehrenberg collection, kept at B, also includes numerous samples acquired from other collectors and shared with Ehrenberg (LAZARUS & JAHN 1998). The Van Heurck collection at BR is another example for this, and of Kützing's collection, for which BM is the principal repository, significant portions can also be found in BR, L, and other herbaria. Grunow gained a fair amount of Kützing's material, thus, it follows that W has retained a substantial amount of original Kützing specimens (ca 500 samples). Grunow's letters, and his collection, show that he was well connected among natural scientists and in particular with other phycologists and diatom specialists. Duplicates may therefore exist in several other collections, but for one reason or another, one institution may have ended up with the single remaining sample though most samples of a given collection are archived at another. For example, W holds most of Grunow's material but a substantial amount is also archived at BR. Through gifts, breakage, loans that were never returned, or other loss of material, some of Grunow's microscope slides no longer exist at W. If the material used to prepare the slides is also no longer available for these reasons or has been used up, individual Grunow slides or material may be present at BR, if at all.

RECHINGER (1914) lists 68 collections made by other phycologists and diatomists, of which material is included in Grunow's collection. Some of the more important ones came from L.A. de Brébisson (Falaise, France), P.T. Cleve (marine algae from St. Thomas, Caribbean), C.G. Ehrenberg (Red Sea material), W.G. Farlow (Alaska, North America), F. Hauck (Adriatic Sea), F. Hauck & P.G. Richter (Phycotheca Universalis exsiccatae), C.G.F. von Hochstetter (New Zealand, SMS Novara expedition), F.T. Kützing (various), F. von Müller (marine algae, Australia), G. de Notaris (various), L. Rabenhorst (algae, Europe), V.B. Wittrock (various) (see RECHINGER 1914 for full list with regions). Another ca 70 collectors contributed additional samples in smaller numbers. Thus, Grunow's collection is international in scope and extent with samples from the Americas, Australasia, Central Europe (extensively so), Japan, the Kerguelen Islands,

◀ Fig. 3: Different preparation types of samples in the Grunow collection: (A) material dried onto pieces of glass or alternatively under mica affixed with gummed linen strips; (B) sample mounted on mica plate shown to the right of the envelope; (C) sediment with diatoms dried onto card, this sample contains *Navicula cryptocephala* KÜTZING, No. 39 from Rabenhorst's exsiccatae series "Algen Sachsens" [Algae of Saxony]; (D) macroalgae with epiphytic diatoms as enclosed in a letter by F. Hauck; (E) Grunow sample 1349 mounted onto a piece of glass with mounting medium, possibly shellac; (F) example of (cleaned) sample mounted onto pieces of glass with a mounting medium, possibly Hyrax. Note that no stable identifiers currently in use at W (QR codes) are shown due to image cropping and that any acquisition numbers seen are obsolete as accession numbers and should not be used in future publications (3F, black arrowhead).



14. **Achnanthes inflata** (Kuetz.?) Grun. Alg. Novara pag. 98, Cl. et Grun. Arct. Diat. p. 19!, *Achnanthes ventricosa* Ehr. Mikrogeol. t. I, f. 3–18-19 non Kuetz., *Stauroneis inflata* Kuetz. Bacill. t. 30, f. 22?, *Monogramma ventricosa* Ehr. Abh. 1843, *Monogramma Smithiana* Grev.? — Quoad formam valvarum maxime varians, apicibus tum rotundatis, tum conoideis, constrictionibus sive profundis sive vix conspicuis, structura ut in *A. subsessili*. 1931

Hab. in lacu «Wahiria-See» dicto in insula Tahiti (Frauenfeld); ad Trapam in fl. «Guayaquil» Æquatoriæ (Istvanffi); in terra eduli Javæ; in *Kieselguhr* pr. «Auckland» (Hochstetter sec. Grunow); ad insulam Trinitatis (Krueger sec. Kuetzing?); in cinere vulcanico insulæ Mauritii (Ehrenberg); in Europa pr. «Pompej» (Heufler) et in Tyrolia australi (Haussmann).

C

the Mediterranean, Oceania, Scandinavia, South Africa, etc., and various research expeditions such as SMS Novara (1857–1859) and the Austro-Hungarian North pole expedition (1872–1874).

This vigorous exchange of material has implications for tracking samples for research, especially type specimens, original and other historical material. For tracking purposes, it is worth noting that a sample in the Grunow collection can have several associated numbers that are not necessarily a collection number. For example:

1. Grunow assigned his own numbers to the samples he worked with, regardless of whether there were already collection numbers for gifted material. However, he retained this information and often noted collection numbers on drawings and in his catalogue (= accession books) in addition to his own sample number. Grunow's catalogue is organised by his sample numbers, which are therefore required to access the information therein. His collection of samples and microscope slides at W is also organised according to these numbers.
2. In addition, there are also the 'de Toni numbers', which refer to the numbering system used in Giovanni Battista DE TONI's "Sylloge Algarum". This is a vast compendium of all algae taxon names, published over a long period of time (1889–1924). Volume 2, in three parts, contains all the then known diatom names (1891, 1892, 1894). Each name was assigned a number; for example, it is 1931 for *Achnanthes inflata* (DE TONI 1891) (Fig. 4, blue arrowhead). De Toni's publications, therefore, include relevant locality information useful for pinpointing original and type material. The 'de Toni numbers' are also relevant, because Grunow's drawing collection at W is organised according to the numbers assigned in the "Sylloge". Studying the drawings is important as Grunow usually noted his sample numbers on each, which is vital for finding raw material and microscope slides at W (Figs 4A, 5 & 6). It also helps to understand how Grunow arrived at his various species concepts. In this respect, another important

◀ Fig. 4: Drawings by Grunow, entries in his accession books, and material covered in DE TONI'S "Sylloge Algarum" (1891, 1892, 1894): (A) Note Grunow's annotations when he prepared the drawing, here on the cut-out remainder showing Grunow sample number (1937), collector and collection number are not given in this case, though the catalogue entry (not shown) reveals it to be a sample collected by Otto Nordstedt s.n. and to correspond to Cleve sample number 57, locality (Dovre [Norway]), the place of publication is not available in this example but is sometimes noted, and scale (1500/0.1 and 1000/1). These drawings were used in VAN HEURCK (1880) as evidenced by the corresponding typeset figure number in that publication and the blueprint copy of the cut-out and original cut-out remainder placed next to each other after reproduction for publication. Note that the cut-outs and remainders of VAN HEURCK figs 8 (blue double arrowhead) and 9 (black arrowheads) have been switched upon assembly on a sheet as can be seen by their outlines, the non-matching figure numbers, and that the cut-out remainder for fig. 8 is missing; (B) Valve coordinate notation in Grunow's accession books (= catalogue) for locating specimens on the corresponding slides. For example (blue arrowhead), in Grunow sample 859 slide "d", a valve of *Hemiaulus polycistinorum* is located at 13.4 mm from the upper and 37.7 mm from the left slide edges. As this notation is circled, this indicates that Grunow made a drawing (not shown); (C) DE TONI (1891) entry for *Achnanthes inflata*. Note "non KUETZ., *Stauroneis inflata* KUETZ. Bacill. t. 30" in the synonyms, and localities Tahiti (French Polynesia), Guayaquil (Ecuador), Java (Indonesia), Auckland (New Zealand), Trinidad, Mauritius, Pompey (Italy), and South Tyrol (Italy). The 'de Toni number', under which any relevant drawings by Grunow will be filed at W, is indicated by a blue arrowhead.

publication is Van Heurck's (1880–1885) "Synopsis des Diatomées de Belgique, Atlas" (Figs 7–9). Although, this important publication contains scant textual information, it is an essential publication as many of the illustrations were prepared by Grunow, and are often the only evidence available for the taxa he described. In the 1800s, an illustration without formal description was sufficient for valid publication of a new taxon (Turland et al. 2018): according to ICN Art. 38.7 "For the purpose of Art. 38.5, prior to 1 January 1908, an illustration with analysis (see Art. 38.9 and 38.10) is acceptable in place of a written description or diagnosis.". Therefore, the plate numbers in Van Heurck (1880–1885) are additional important information for ascertaining type material. Moreover, Grunow's copy of Van Heurck (1880–1885) at W is, in some cases, annotated by him with his sample number citing the original material for the illustrated valve, which again helps to pinpoint type material (Fig. 9). Plates 22Bis. and 33–132 in Van Heurck's "Types du Synopsis des Diatomées de Belgique, Atlas" (1882–1885) have annotations.

3. Additional numbers, on the capsules in particular, are now obsolete W acquisition numbers (e. g. "(Acqu.) 1901–1234", with 1901 referring to the year the Grunow diatom collection was officially accessioned at W, Figs 2A, blue arrowhead & 3F, black arrowhead). These are now replaced by a numeric QR code, which is the unique persistent identifier (PID) used for citation in publications and other tracking purposes of W specimens (e. g. W0012345). As an example, this is the format for W stable identifier citation: https://w.jacq.org/W0012345 (dummy URL), with the W-number corresponding to the QR code (always seven digits) and JACQ (2021) being the W online database.
4. Grunow sometimes used a specific shorthand for dates. For example, 4/868 is not another numbering system, but denotes a collection made on or a publication date of April 1868 (David Mann, pers. comm.).
5. Grunow used a coordinate system denoting the location of specific valves on his microscope slides, such as 'd 13.4/37.7' (see section below, Fig. 4B, blue arrowhead).
6. Lastly, in some cases there are collection numbers assigned by collectors that sent their material to Grunow. Though, as is often the case with historical specimens, they were just as often collected sine numero (s.n.), i. e. without collection number.

Components of and object types included in the Grunow collection at W

Grunow's diatom collection at W includes a great variety of sample preparation types and other relevant objects, such as drawings and books. The following section introduces these visually, while the next lays out their organisation at W. Note that no stable identifiers currently in use at W (QR codes) are shown in the figures, as these will be systematically added to the collection during its future digitisation, and that any acquisition numbers seen are obsolete for publication.

Loose diatomaceous material (Figs 2A–2D)

This original material is kept in various receptacles, and therefore separate parts of the collection, such as packets (Fig. 2A), glass vials (Fig. 2B), larger bottles containing chunks of rock (Fig. 2C), and fossil diatom samples kept in historical pillboxes (Fig. 2D).

Sediment and phorophytes dried onto various materials (Figs 3A–3D)

Sediment with diatoms is present either dried onto pieces of glass without a coverslip or alternatively under mica affixed with gummed linen strips (Fig. 3A), just mica (Fig. 3B), or card (Fig. 3C). Macroalgae with epiphytic diatoms as enclosed in a letter to Grunow by F. Hauck (Fig. 3D) are also part of the collection.

Cleaned, mounted samples (Figs 3E & 3F)

Some (cleaned) samples are preserved on small, roughly rectangular pieces of glass using mica or glass cover slips sealed with various media such as likely shellac (Fig. 3E) and Hyrax (Fig. 3F). These glass pieces are usually smaller and thicker than a modern standard glass slide for microscopy, and are therefore difficult to work with on a microscope stage.

Glass slides (Fig. 10)

Of the 3,386 of Grunow's microscope slides (Mario-Dominik Riedl, pers. comm.) some 1,400 are still available for study at W. The Nebensammlungen (accessory collections) include slides made by current researchers from Grunow material returned to W and ca 300 duplicates of Grunow's slides (not shown). The slides can be examined for specimens and light micrographs can be captured for publication, as well as representing type material. Oil immersion at 1000x is possible for many of these historical slides, though some are too fragile to allow this.

Drawings (Figs 5 & 6)

The drawings are either Grunow's own careful work (denoted by his sample number and sometimes specimen coordinates for the slides), or copies of other's drawings in order to amass a more or less complete visual catalogue of all diatom taxa. Grunow made thousands of drawings. Shown are those for *Achnanthes inflata* (KÜTZING) GRUNOW, the example taxon discussed throughout this paper (Figs 5 & 6). The collection also includes those drawings used in publications, mostly in VAN HEURCK (1880–1885). These are visually obvious (Fig. 4A) in that they consist of a cut-out (as a blueprint copy) of the drawn valve roughly along its outline and with a type set figure number, glued next to the piece of paper from which this was extracted (termed cut-out remainder here) with Grunow's annotations when he prepared the drawing (e. g. Grunow sample number, collector and collection number, locality, place of publication, scale). See the section on Grunow's catalogue below for his specimen finder notation system (coordinates).

Annotated copy of VAN HEURCK (1880–1885, Figs 7–9)

This is a set of volumes of VAN HEURCK's "Synopsis des Diatomées de Belgique, Atlas" annotated with the Grunow sample numbers of material used to prepare the featured drawings. Grunow stated that he prepared approximately two thirds of the "Synopsis" published by VAN HEURCK (1880–1885) (RECHINGER 1915), which includes many descriptions, mainly as illustrations. The drawings were selected from among Grunow's many thousands of sketches. This is evidenced by those drawings having been cut out to isolate the illustration only, leaving notes and annotations behind on the remaining piece of paper (cut-out remainder), and indicating the figure number in VAN HEURCK

(1880–1885) in type. Because the original cut-outs stayed with Van Heurck (now at BR), at W, blueprint copies were substituted in the Grunow collection and are visually obvious due to the blue colouring. Fig. 4A shows a rare case where a mistake occurred during assembly of the drawings on sheets, as the cut-outs and cut-out remainders have been switched for *Navicula serians* var. *brachysira* (Brébisson) van Heurck (as *N. serians* var. *minor* Grunow) and *N. serians* var. *minima* Grunow used for Van Heurck (1880) pl. 12, figs 8 & 9. Grunow annotated his copy of Van Heurck (1880–1885), noting in pencil which particular sample he worked from to generate the illustrations used therein, though he did not do this consistently for all illustrations, and annotations, in particular for the earlier plates, are lacking (1–32, except 22Bis.). For example, compare the reproductions in Figs 7 (Van Heurck 1880, pl. 26) and 8 (Van Heurck 1880, pl. 27) with no annotations, to the reproduction in Fig. 9, which is an annotated plate (Van Heurck 1883, pl. 112).

Catalogue – accession books (Fig. 11)

Grunow kept track of the material he worked on in a catalogue consisting of five composition notebooks. Therein, samples are organised according to ascending numbers (see point 1. above); he also jotted down information about the sample, such as locality, collector, collection date, in varying detail and listed some of the principal taxa in the sample. Grunow also had a notation system for locating particular valves on slides, which is on some drawings and occasionally in the catalogue. For example, in the accession books ‘d 13.4/37.7’ shown for Grunow sample 859 (Fig. 4B, blue arrowhead) refers to slide ‘d’ of sample number 859, of which Grunow prepared four slides, and gives valve location on that slide as 13.4 mm from the upper, and 37.7 mm from the left edges. As ‘d 13.4/37.7’ is encircled, this means that Grunow also made a drawing. This notation is relatively rare in the accession books, as indicated by the first instance at Grunow number 859 out of 3,278, nor is this notation frequent thereafter. It is more often encountered on the drawings (e. g. the drawing for sample number 2311.a in Fig. 6). As an aside, note that slides 859b and 859d are missing from the collection.

For completeness, there are other non-diatomaceous parts of the Grunow collection at W, such as his macroalgae and *Sargassum* C.Agardh collections (Figs 12 & 13) donated in 1912 (Rechinger 1915).

Organisation and management of the Grunow collection at W

At W, the diatom specimens are kept in the cryptogam collection, separate from the phanerogams (see Bräuchler et al. 2021 for a more detailed overview). The collection is mainly that of Grunow, who donated his collections to W: the diatoms were donated in 1899 (Anonymous 1899), of which 6,144 sample numbers were officially accessioned in 1900 and 1901 in addition to thousands of drawings (Steindachner 1902), and later, in 1912, the remainder of his algae collection (Rechinger 1915). Since then, the Grunow diatom samples are kept in two larger separate sets, which are not congruent in that samples may be represented in one, but not necessarily the other as well. These are kept in one set according to Grunow’s numbering system (Fig. 14) and another set as general collection (Fig. 15). Some samples may be filed in one set, but not the other, which makes locating material complex:

1. a general collection organised alphabetically by genus and species, containing many duplicates of Grunow sample numbers, but also other material and
2. a set organised by Grunow's sample numbers.

In addition, there are several sub-collections kept separately for management purposes (storage of different preparation types) and historical reasons. For example, due to space issues at the herbarium, the drawings were at one point kept in a different NHMW department, the Archive for the History of Science, but have since been returned to the herbarium on permanent loan as they are essential for finding type material and understanding Grunow's ideas about diatom taxonomy (see below). The collection is not yet digitised and numbers given here are mostly estimates. Grunow's catalogue, as listed in his accession books, numbers 3,278 entries corresponding to ca 1,450 microscope slides, both organised according to the number Grunow assigned each sample. There are fewer slides than sample numbers as some were gifted to Grunow's collaborators or by subsequent curators to researchers, have been lost through unreturned loans, or breakage during transport. In order to preserve this invaluable original material, the slides are now therefore no longer sent out on loan. It is important to note that neither is the raw material for all 3,278 samples still available at W. Additional separate exsiccatae that once belonged to Grunow are CLEVE & MÖLLER's "Diatoms" (1877–1882), MÖLLER's "Probe- und andere Platten" (1868), DELOGNE's "Diatomees de Belgique" (1880–1881), EULENSTEIN's "Diatomacearum Species Typicae" (1867–1869), RABENHORST's "Diatomaceae exsiccatae totius terrarum orbis" (1871), and VAN HEURCK's "Types du Synopsis des Diatomées de Belgique" (1882–1885). Additional small ancillary sub-collections of samples without a Grunow sample number are: fossil material, cleaned material in liquid, slides prepared by current researchers, and SEM stubs. Except for the sine numero samples, these are organised according to Grunow sample numbers. It should be noted that some material Grunow worked with, such as that of Per Teodor Cleve, Henri Van Heurck, and George A. Walker Arnott, no raw material exists at W, but part of it (Van Heurck, Walker Arnott) is archived at BR, BM (Walker Arnott), and the herbarium of the Royal Botanic Garden Edinburgh (E, Scotland, UK).

Grunow's diatom drawing collection numbers in the many thousands. Several drawings are assembled onto a sheet and these are kept in species maps organised according to the numbering system of DE TONI's (1891, 1892, 1894) "Sylloge Algarum" (Figs 5 & 6 and see point 1. below). This was done by a team of preparators and assistants at the Department of Botany, and the ordering according to genus and species names, mounting onto sheets, and organisation into maps were directed by volunteer K. von Keissler (STEINDACHNER 1901, 1902), who later became director of the department (in those days it was expected to start in an unpaid role (BRÄUCHLER et al. 2021)). The drawing collection also comprises those used in publications, such as VAN HEURCK (1880–1885), which were cut out of the original sheets. These extracted drawings are conserved in BR as they have the original (handmade) plates of VAN HEURCK (1880–1885) in their collection. The shape of the original cut-outs (BR) corresponds entirely with the cut-out remainder in the Grunow collection (W) as evidenced by the blueprint copies of the original cut-outs (also at W) (Fig. 4A).

Digital scans of a small number of drawings and the annotated copy of VAN HEURCK's (1880–1885) "Atlas" can be generated and shared upon request to the curator of cryptogams (see below). Scans of the accession books exist and portions of these

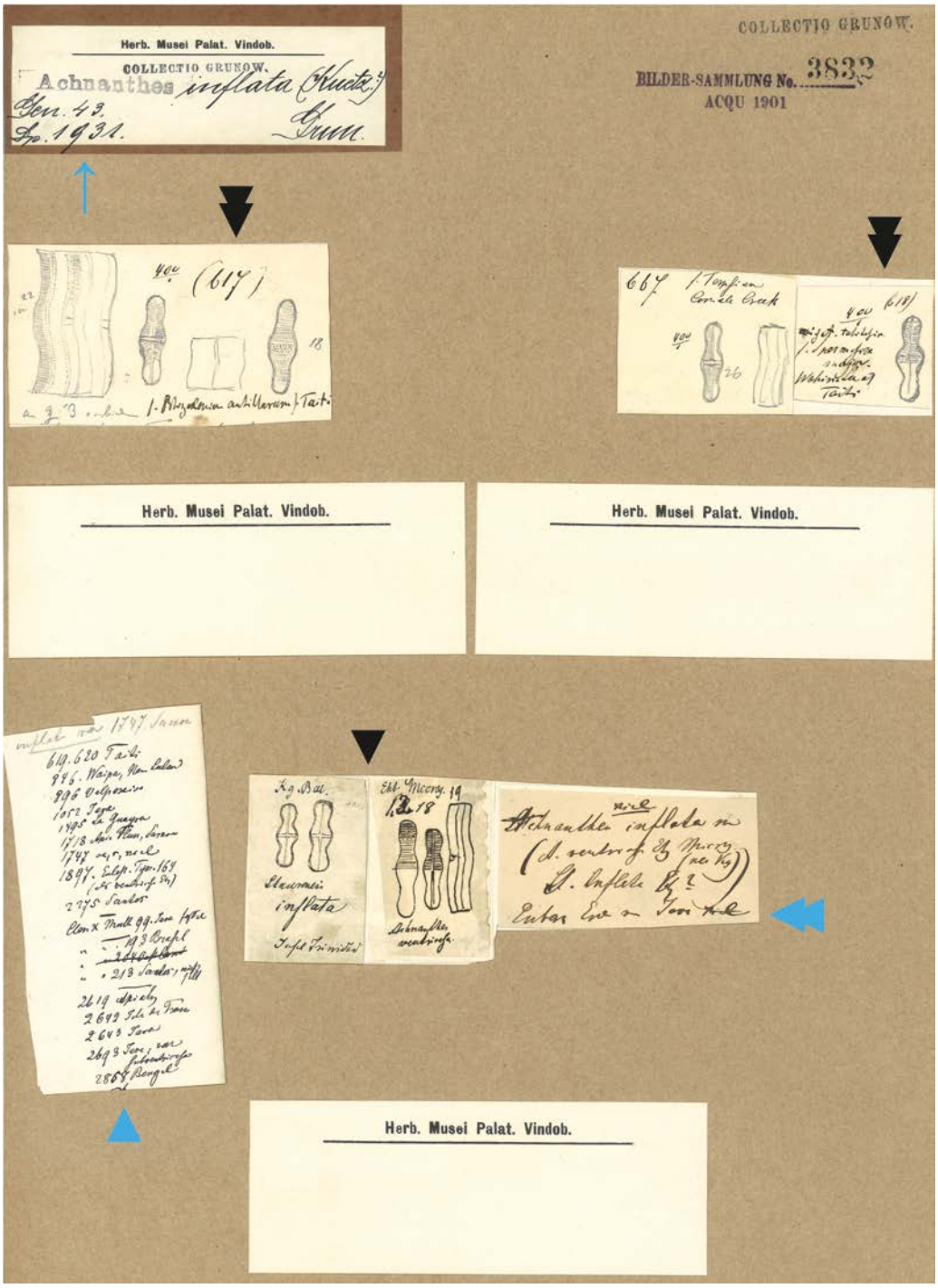
high-resolution scans can also be made available upon request until the Grunow collection is fully digitised and published online. To this end, staff at W are in the process of digitising the Grunow collection to make it more accessible to users globally via the herbarium's online platform JACQ (2021). This process, the rationale behind it, and workflows will be discussed in a future publication.

Procedure for finding a specimen in the Grunow collection at W – Using *Achnanthes inflata* (Kützing) Grunow as example

The following sequence of steps involving the component parts of the Grunow collection usually lead to finding relevant original and type material as well as other historical material. We chose *Achnanthes inflata* (Kützing) Grunow (basionym, *Stauroneis inflata* Kützing) as example, because it is currently being worked on for a future publication. The concepts of *A. inflata* sensu Grunow relative to *S. inflata* sensu Kützing need closer examination, as it is not clear that they are conspecific. Hence, locating Grunow's material for re-examination was important. This example is sufficiently complex to showcase the many interlinked layers of the Grunow collection at W. The different components of the Grunow collection are consulted in the following sequence:

1. de Toni's (1891, 1892, 1894) "Sylloge Algarum". Entries for species in the "Sylloge Algarum" often include information on the samples Grunow used for descriptions (though they do not indicate the actual Grunow sample number), their collectors and localities, which are needed in conjunction with the drawings. Finding the relevant entry requires going through the index and locating the assigned taxon number code ('de Toni number') shown in the text margin by the species name (Fig. 4C, blue arrowhead). The 'de Toni number' is essential for finding Grunow's drawings for that particular taxon, as the drawing collection is organised according to these numbers. This in turn leads to pinpointing the Grunow sample numbers noted on most of the drawings, which lead to the accession book entries, raw material samples, and microscope slides. The de Toni number for *Achnanthes inflata* is 1931 (Figs 4C, blue arrowhead & 5, blue arrow).
2. Drawings (Figs 5 & 6). The map of drawings for *A. inflata* shows a list of sample numbers and their localities (Fig. 5, blue arrowhead), and individual drawings with annotations for some of those sample numbers. Note that the list gives Grunow sample numbers in which *A. inflata* occurs, according to him. However, the lists are not always available, nor are they necessarily complete. For example, note Grunow's annotation (Fig. 5, blue double arrowheads) for *A. inflata* referring to "essbare Erde von Java" [edible soil from Java], which corresponds to the unique

Fig. 5: Grunow's drawings for *Achnanthes inflata* (Kützing) Grunow: as seen on the label of the map that contains the drawings for *A. inflata*, which is shown as inset in the upper left-hand corner, the drawing collection is organised according to the numbering system of de Toni (1891, 1892, 1894), i. e. number 1931 for this taxon (blue arrow). The blue arrowhead indicates Grunow's list of his sample numbers that include *A. inflata* and their collection localities. The blue double arrowhead points to Grunow's annotation slip for *A. inflata* and its synonymy, referencing a sample of "essbare Erde von Java" [edible soil from Java]. The black arrowhead points to further synonyms. The black double arrowheads indicate Grunow samples 617 & 618 from Tahiti. ▶


Herb. Musei Palat. Vindob.
COLLECTIO GRUNOW.
Achnanthes inflata (Kütz.)
Ser. 43.
Sp. 1931.
Grun.
COLLECTIO GRUNOW.
BILDER-SAMMLUNG No. 3832
ACQU 1901
Herb. Musei Palat. Vindob.
Herb. Musei Palat. Vindob.
Herb. Musei Palat. Vindob.

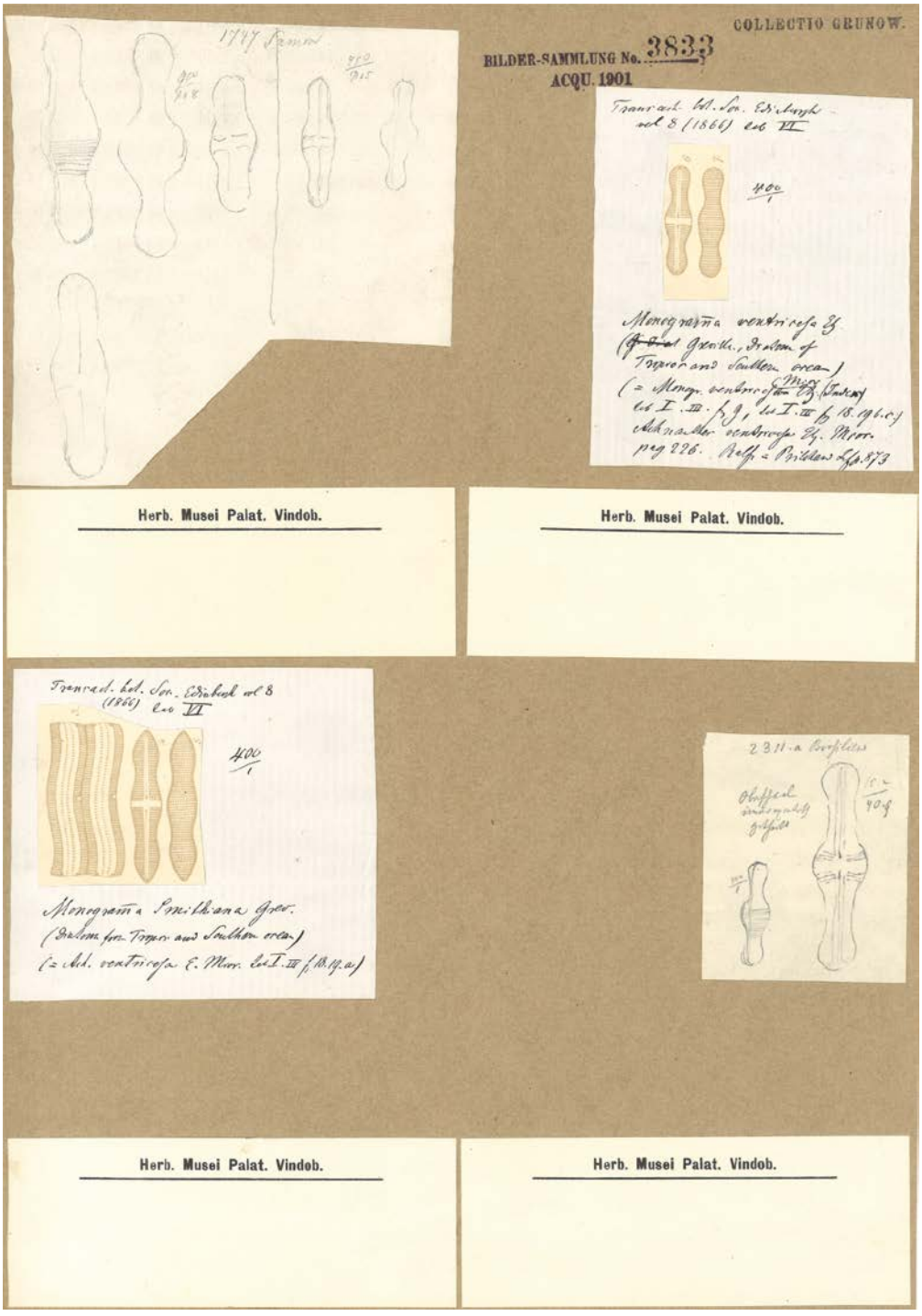


Fig. 6: Grunow's drawings for *Achnanthes inflata* (KÜTZING) GRUNOW: for completeness, the second sheet of drawings for *A. inflata* in that map is shown here.

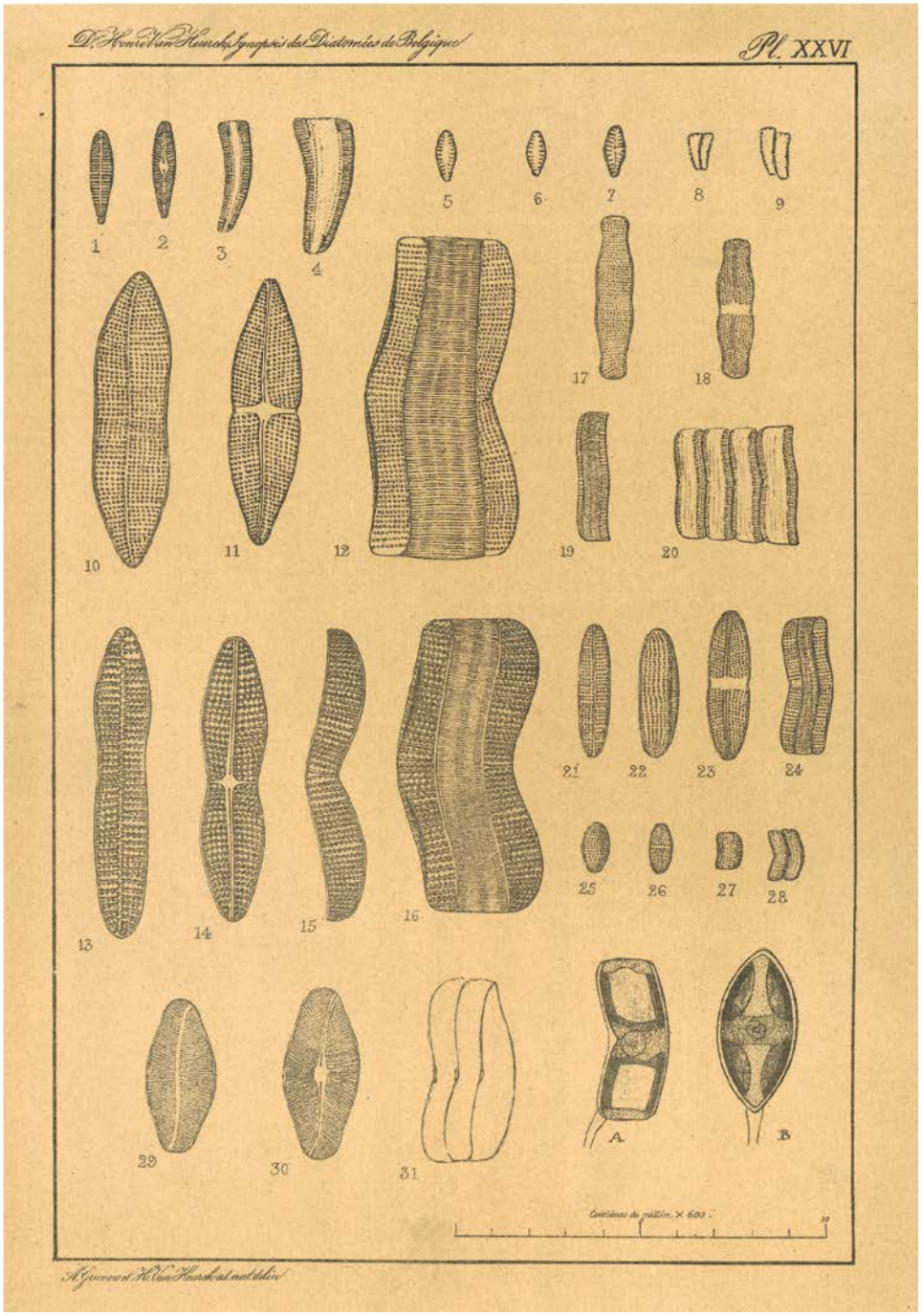


Fig. 7: Grunow's drawings in Van Heurck's publications: plate 26 in VAN HEURCK (1880) for *Achnanthes* (figs 10–28) without any annotations about Grunow sample numbers used to prepare the illustrations. Compare to plate 112 in VAN HEURCK (1883) of the unrelated *Triceratium* EHRENBERG where annotations are given (see Fig. 9).

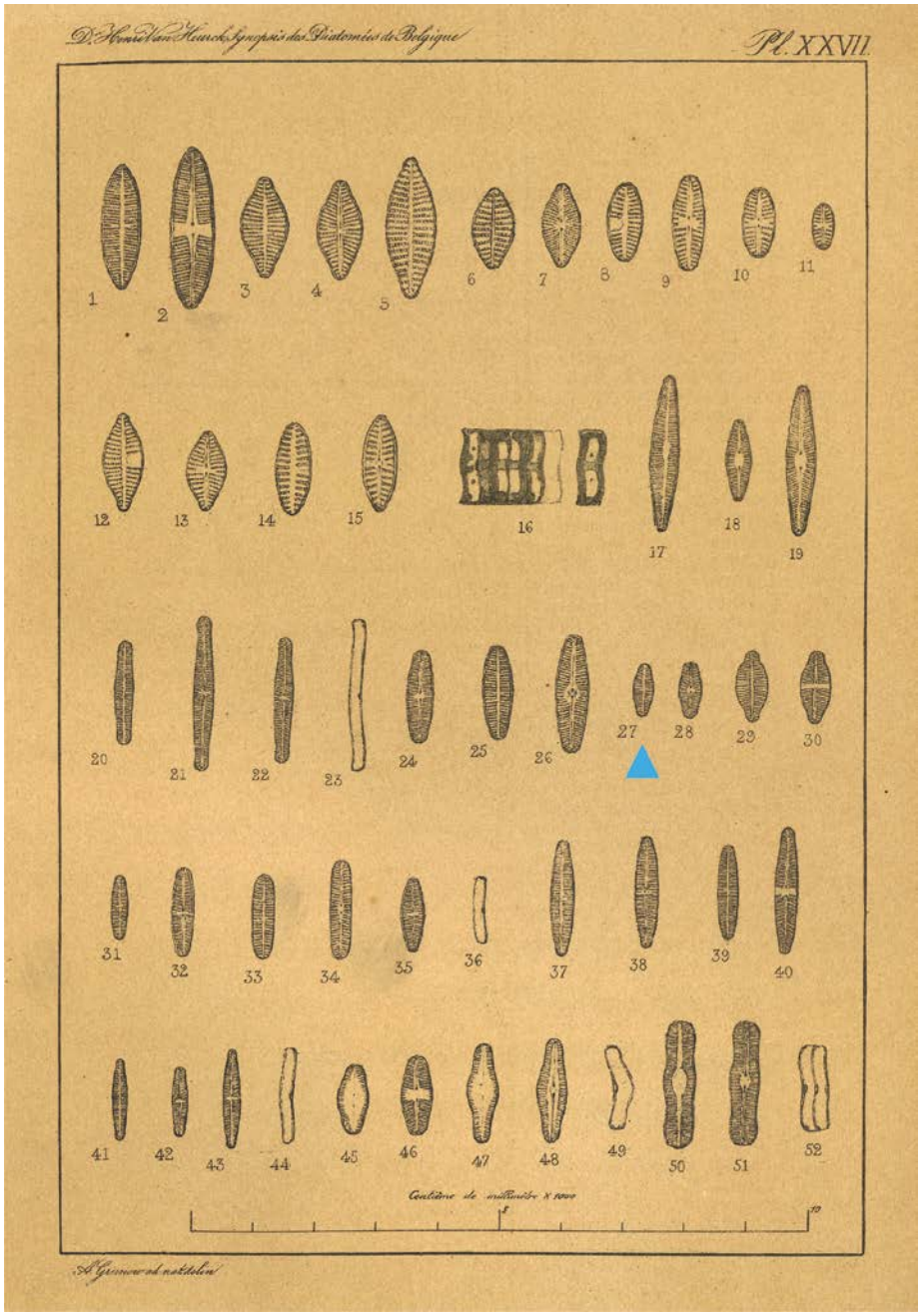


Fig. 8: Grunow's drawings in Van Heurck's publications: plate 27 in Van Heurck (1880) for *Achnanthes* (all figs) lacking annotations. The caption for fig. 27 references "*A. ventricosa*?" (blue arrowhead, text not shown). Plates for *Stauroneis* Ehrenberg (Van Heurck 1885, pl. 4, 7, 10, 12, 13, 14, 27 in Van Heurck (1880)) are also not annotated (not shown). Therefore, all of Grunow's drawings for *A. inflata* and its synonyms have to be further consulted in relation to the protologue to pinpoint Grunow's original material.

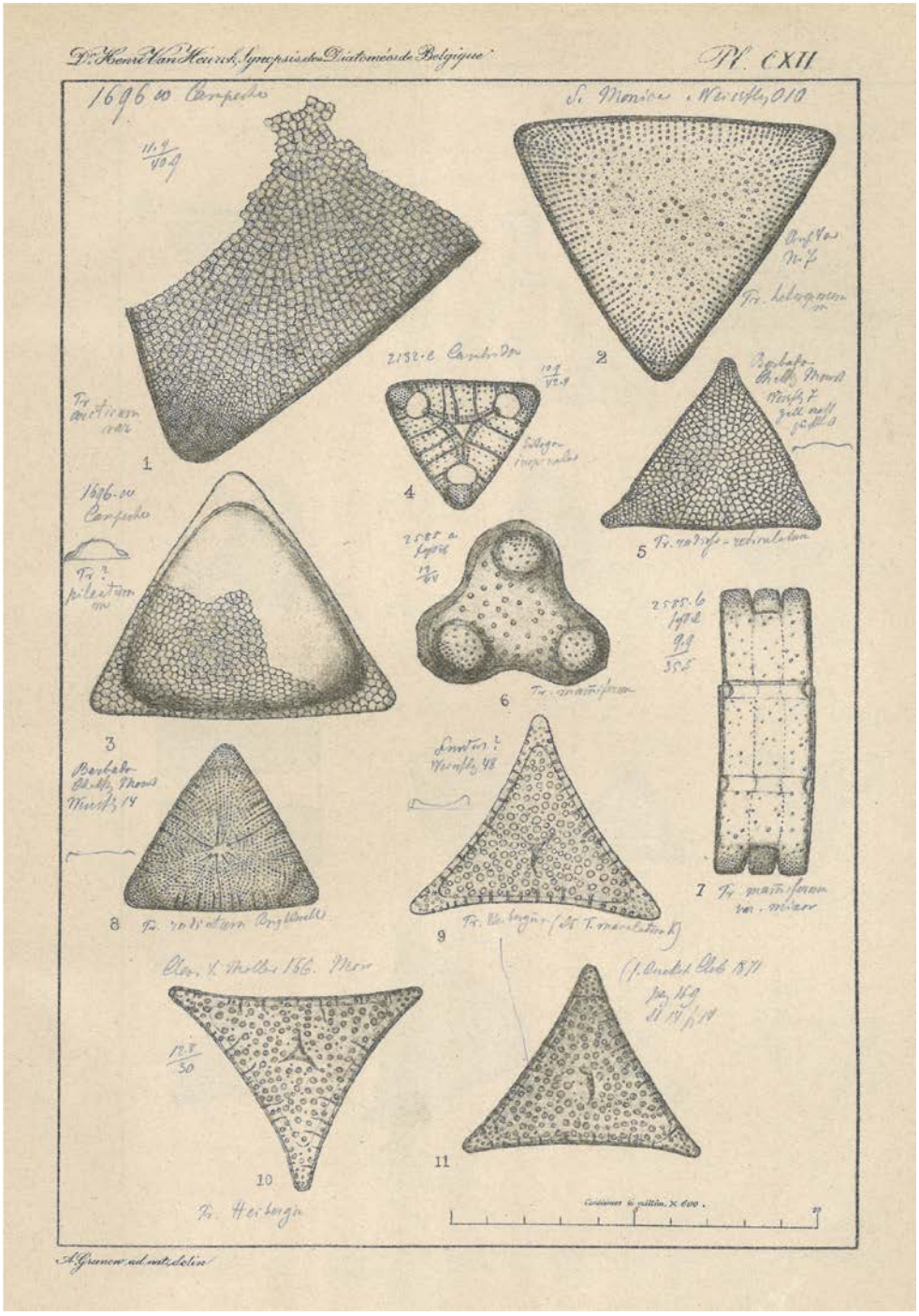


Fig. 9: Grunow's drawings in Van Heurck's publications: for comparison to the two previous plates, a plate (VAN HEURCK (1883), pl. 112) annotated with the Grunow sample numbers of material used to prepare the featured drawings of species of *Triceratium*.

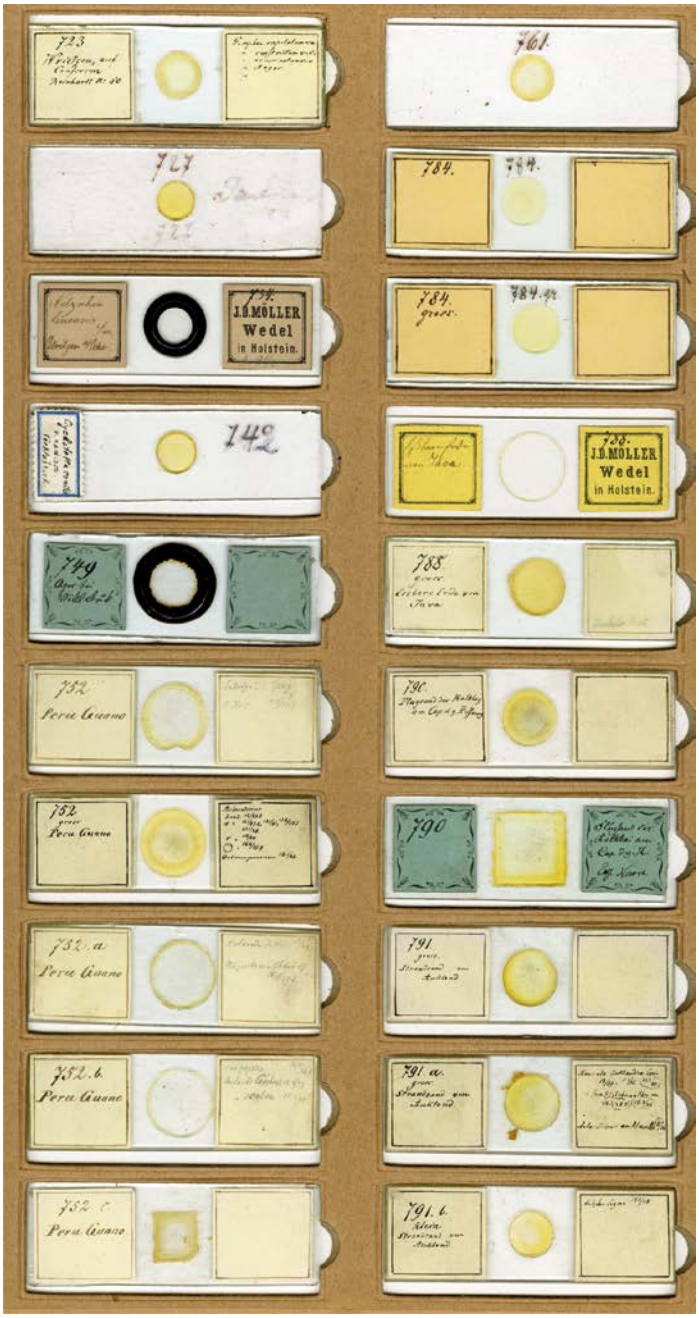


Fig. 10: Microscope slides prepared by Grunow showing organisation within a pop-up slide holder according to Grunow sample numbers: there are two slides for Grunow sample 788. The label on both slides reads “Essbare Erde von Java” [edible soil from Java]. The label on the second slide reads “gross” [large] and has a note in pencil: Denkler 2ck. The other slide has an additional exsiccatae label: “J.D.Möller, Wedel, in Holstein”. The slides can be examined for specimens to generate light micrographs for publications and represent the type material.

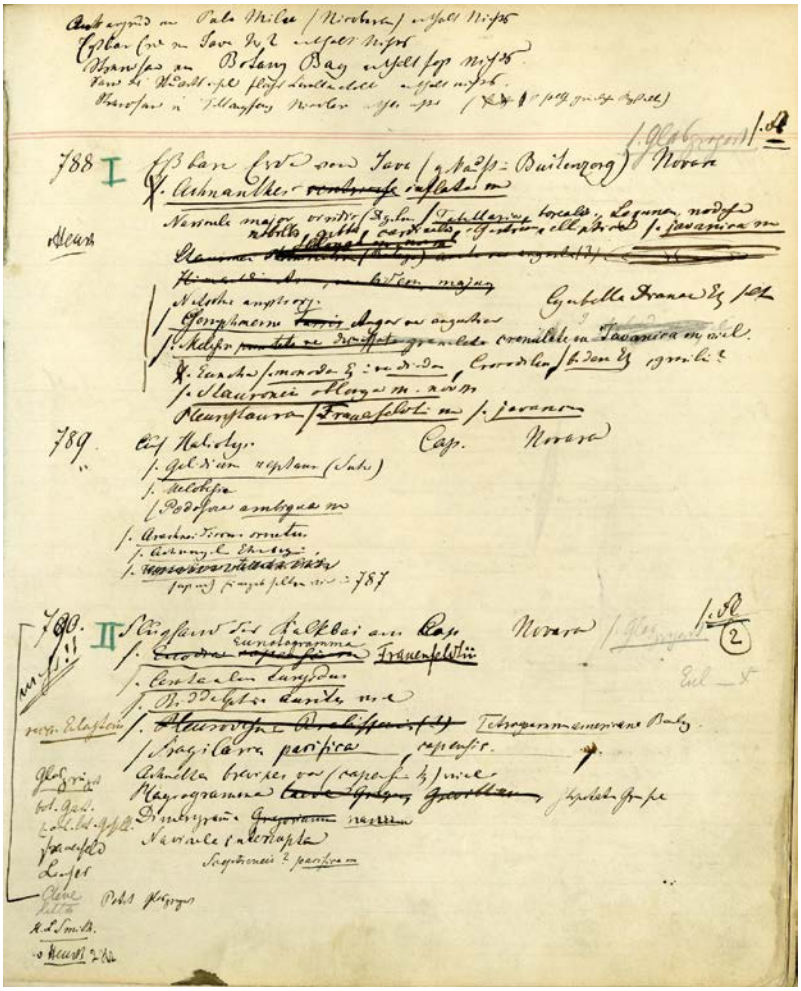


Fig. 11: accession book entry for Grunow sample 788: the text reads (though characteristically partially illegible):
I [in green wax pencil, it is unclear what this refers to].
V[an] Heurck.
Essbare Erde von Java (gekauft – Buitenzorg) [edible soil from Java (bought – Bogor)] Novara [Expedition] /. glas preparat [? in pencil]/. fl
X. *Achnanthes ~~ventricosa~~ inflata* m[ihi]
Navicula major viridis, (*Digi*[illegible] / *Tabellaria*, *borealis*., *Legumen*, *nodosa nobilis*, *gibba*, *cardinalis*, *gastrum*, *elliptica* /. *javanica* m.
~~Stauroneis~~ [~~illegible~~]
[~~illegible~~]
Nitzschia amphioxys Cymbella Dianae Eh [Ehrenberg] /. et
/ *Gomphonema ~~Turris~~ Augur* var. *angustata*
/. *Melosira* [~~illegible~~] *~~granulata~~ crenulata* var. *Javanica* m [illegible].
X. *Eunotia* /. *monodon* Eh: var *diodon*, *Crocodilus* / *bidens* Eh, *gracilis*?
/. *Stauroneis oblonga* m. nov m
Pleurostauron / *Frauenfeldtii* m /. *javanica*

Fig. 12: A drawing of *Chara armata* MEYEN ex KÜTZING by Grunow from the macroalgae collection.

Fig. 13: Grunow's macroalgae collection of *Sargassum* represented by a specimen of *S. amaliae* GRUNOW collected in Australia in the 19th c. by Amalie Dietrich (blue arrowhead), an early German female naturalist in whose honour Grunow named this species.

Fig. 14: Organisation of raw materials in the Grunow collection: an example of map contents within the collection set filed according to Grunow sample numbers. Grunow sample 788 is not shown as it is out on loan.

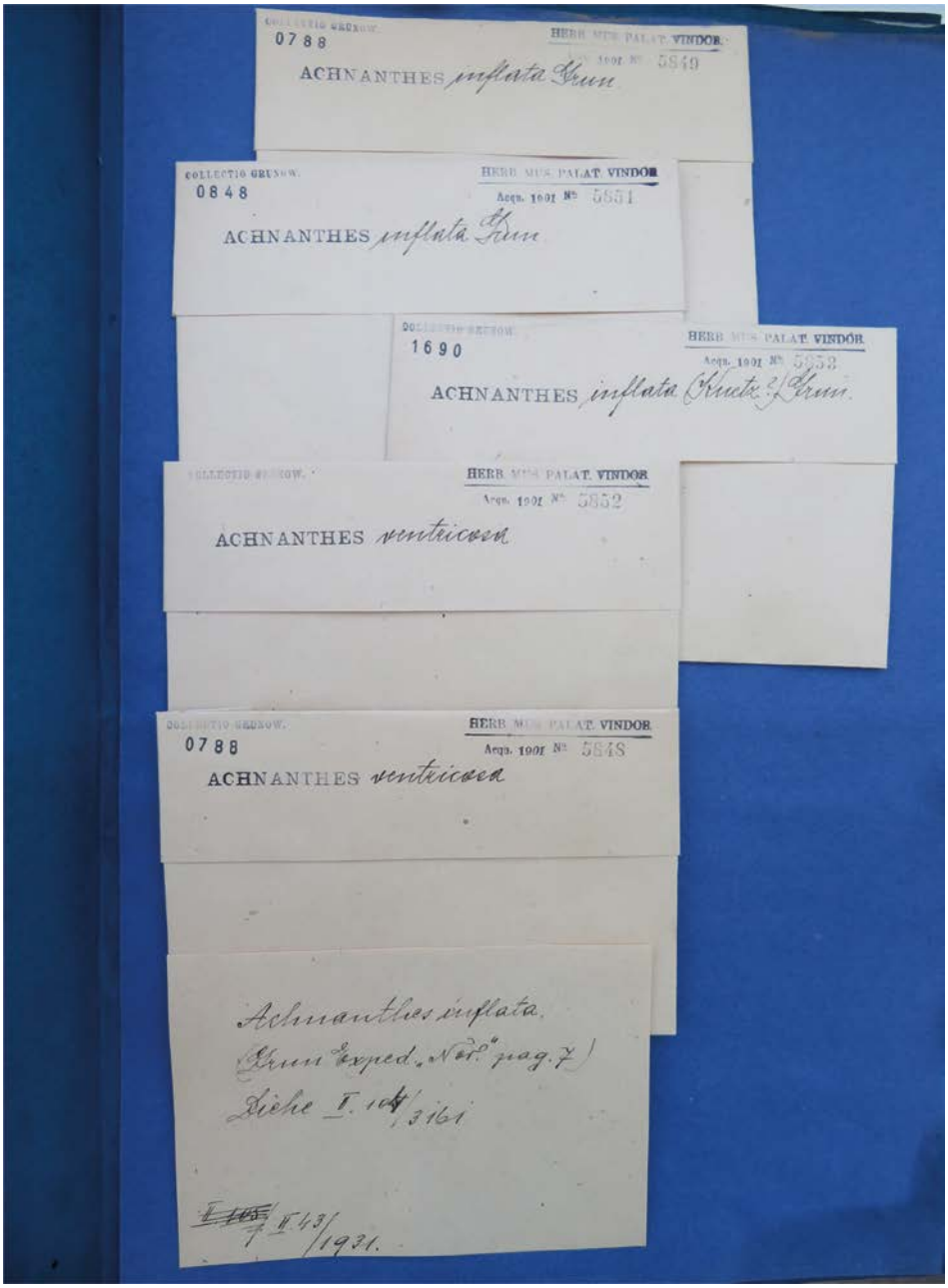


Fig. 15: Organisation of raw materials in the Grunow collection: general collection set filed alphabetically according to genus and species with capsules of multiple samples gathered in a map. The map containing samples for *Achnanthes inflata* (KÜTZING) GRUNOW is shown. Note availability of two capsules with material from Grunow sample 788 collected during the SMS Novara expedition (also see Fig. 3F). Grunow sample 848 corresponds to Hochstetter s.n. collected at Cabbage Tree Swamp, Auckland, New Zealand and Grunow sample 1690 corresponds to Kurz 3175 (collector) and Hauck sample number 799, Pegu [Range], Burma (= Bago Yoma, Myanmar).

Grunow sample 788 (fossil, Fig. 2D), but is not listed. The annotation also gives its synonym *A. ventricosa* Ehrenberg (as Ebg.) [in] Microg., nec Kg. [Kützing] and registers Grunow's doubt, as indicated by "?", whether it is conspecific with *Stauroneis inflata* Kützing depicted between the list and annotation slip (Fig. 5, black arrowhead). Also note that Grunow samples 617 and 618 from Tahiti are depicted on the sheet (Fig. 5, black double arrowheads). Java and Tahiti are the two localities listed in the protologue for *A. inflata*, Grunow (1867). Sometimes, annotations in Grunow's copy of Van Heurck (1880–1885) help to narrow the selection to a single sample number or the type material.

3. Annotated copy of Van Heurck's "Synopsis des Diatomées de Belgique, Atlas" (1880–1885) (Figs 7–9). There are no examples of *Achnanthes inflata* in Van Heurck (1880–1885), nor are the *Achnanthes* plates annotated (Figs 7 & 8), so all of Grunow's drawings for *A. inflata* need to be consulted further (Figs 5 & 6) in conjunction with the localities given in the protologue and de Toni (1891). In the protologue Grunow (1867) provides two SMS Novara expedition localities: 1) Java, a sample of edible soil, collector unknown and 2) Wahiria See (Lake Vaihiria), Tahiti collected by Frauenfeld s.n. Tahiti is noted on the drawings for Grunow sample numbers 617 and 618 (Fig. 5, black double arrowheads), and one note with "essbare Erde von Java" (Fig. 5, blue double arrowhead), which implicates the unique fossil sample 788, though the number is not listed. Sample 788 was purchased at a market in Bogor, Indonesia, [am Markt von Buitenzorg gekauft] (see pill box label Fig. 2D, blue arrowhead). Since annotations in Van Heurck do not narrow down the selection here, material from all samples Grunow listed still available should be examined, but particularly those from Java and Tahiti.

4. Catalogue (= accession books). The accession books give further details for each sample number, such as a species list for the sample, often indicating the most common species present by underlining them or possibly with the notation "1. or /.", and provenance information, such as its collector, collection locality, and sometimes other notes. The entry for Grunow sample 788 is shown (Fig. 11) and corroborates that this number corresponds to the sample "essbare Erde von Java" and was purchased during the SMS Novara expedition. Entries for Grunow samples 617 and 618 (not shown) give Tahiti, and specifically "Lake Wahiria" for the latter, record von Frauenfeld as collector, and list *Achnanthes ~~frauenfeldii~~ inflata* m (617) and *Stauroneis frauenfeldii* (618).

5. Microscope slides. Note in Fig. 10 that two slides for Grunow sample 788 are available, and again reference "essbare Erde von Java". The slides for Grunow samples 617 and 618 are no longer available at W. Slides corresponding to Grunow samples mentioned in the list included in the map of drawings or annotations therein and still available for light microscopy (LM) study are: 667, 846, 848, 1495, 1690, 1718, 1747a & b, 1897, 2275, 2311a & b, 2619a & b, 2642, 2643, 2693, and 2868.

6. Raw material collections. Regarding *A. inflata*, in the set filed according to Grunow numbers, raw material is available for sample 788, but not numbers 617 and 618. The general collection includes Grunow sample numbers 788, 848, and 1690 filed under the name *A. inflata* (Fig. 15), and 617 (= Frauenfeld s.n., Tahiti) filed under *Gomphonema parvulum* (note that diatom samples usually include several

taxa) with none available for sample 618. Based on GRUNOW (1867), samples 788 (Java) and 617 (Tahiti) could be examined more closely using SEM. Grunow sample 848 (= Hochstetter s.n., Cabbage Tree Swamp, Auckland, New Zealand), another collector and locality mentioned in GRUNOW (1867) and DE TONI (1891) with less detail (Fig. 4C), and Grunow sample 1690 (= Kurz 3175 (collector) and Hauck sample number 799, Pegu [Range], Burma = Bago Yoma, Myanmar) may also be relevant though the latter was not explicitly mentioned in the protologue. Only if ample raw material is available can it potentially be destructively sampled to make preparations for LM and SEM work, which is the case here. Based on the results, a publication by D.M. Williams about the identity of *S. inflata* sensu KÜTZING relative to *A. inflata* sensu GRUNOW will appear elsewhere once these samples have been examined.

Submitting requests to W for the Grunow collection

To speed up requests, it is helpful to supply the following information:

1. The Grunow sample number (if known)
2. 'de Toni number', i. e. the number assigned to a taxon in DE TONI's (1891, 1892, 1894) "Sylloge Algarum". The volumes are freely available here:

   1891: https://bibdigital.rjb.csic.es/idurl/1/10558

   1892: https://bibdigital.rjb.csic.es/idurl/1/10559

   1894: https://bibdigital.rjb.csic.es/idurl/1/10560
3. Plate number in VAN HEURCK's (1880–1885) "Synopsis des Diatomées de Belgique, Atlas", available here: https://gallica.bnf.fr/ark:/12148/bpt6k62251160.texteImage
4. A scan of the protologue
5. Drawings or LM images of the taxon in question
6. Any other information the requester thinks relevant

Please note that due to their uniqueness and fragility Grunow's microscope slides can no longer be sent out on loan nor in many cases examined using oil immersion methods. Until they are published online on the W herbarium data platform JACQ (2021), a few scans of selected pages of the catalogue (accession books), VAN HEURCK's (1880–1885) "Atlas" annotated with sample numbers by Grunow, and drawings can be made available upon request.

Online Supplementary Material

Publications by Albert Grunow as listed in MILLS (1893) and RECHINGER (1915) with some additions

All works by Grunow are listed in the online supplementary material associated with this article, in the online version, at http://www. nhm-wien.ac.at/verlag/wissenschaftliche_publikationen/annalen_serie_b/124_2022.

Several entries in the list are short notes by him on the publications of others, but nonetheless often contain pertinent taxonomic information. These notes show which literature Grunow was aware of and may have influenced him. His main publications are those on the genus *Sargassum* (Grunow 1867, 1915, 1916) as well as *Schizonema* C.Agardh and *Berkeleya* Greville (Grunow 1868, 1880), his analyses of the diatoms collected during the Novara expedition (Grunow 1867, 1869), analyses of the algae from the Austro-Hungarian North pole expedition (1872–1874) led by Weyprecht and Payer when discovering parts of Franz Josef Land (Grunow 1884), and work on "Synopsis des Diatomées de Belgique, Atlas" (largely prepared by Grunow, but published as Van Heurck 1880–1885). Grunow was also an editor for the multi-volume "Dr. L. Rabenhorst's Kryptogamen-Flora von Deutschland, Österreich und der Schweiz" and contributed to "A. Schmidt's Atlas der Diatom(ac)een-Kunde".

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