Biodata of **Aharon Oren**, author of ***"Paper from Outer Space – On "Meteorpapier" and Microbial Mats"***

Aharon Oren is Professor of Microbial Ecology at the Institute of Life Sciences, The Hebrew University of Jerusalem. He earned his Ph.D. at the Hebrew University in 1978, and spent a postdoctoral period at the University of Illinois at Urbana-Champaign. His research centers on the ecology, physiology, biochemistry, and taxonomy of halophilic microorganisms and the microbiology of hypersaline environments.

E-mail: **orena@cc.huji.ac.il**

J. Seckbach and A. Oren (eds.), *Microbial Mats: Modern and Ancient Microorganisms in Stratified Systems*, Cellular Origin, Life in Extreme Habitats and Astrobiology 14, 27–38
DOI 10.1007/978-90-481-3799-2_2,

PAPER FROM OUTER SPACE – ON "METEORPAPIER" AND MICROBIAL MATS

AHARON OREN
Department of Plant and Environmental Sciences, The Institute of Life Sciences, and the Moshe Shilo Minerva Center for Marine Biogeochemistry, The Hebrew University of Jerusalem, 91904 Jerusalem, Israel

1. Introduction

> In einer Zeit, in der einerseits empfindliche Papierkrappheit und andererseits beinahe ausschließlicher Papiergeltumlauf herrschen, in der wir in Ermangelung anderer Rohstoffe unsere Wäsche, Kleider, Decken, Vorhänge und selbst Bindfaden aus Papier herstellen, ist es vielleicht angebracht, einer besonderen Art von Papier zu gedenken, das fast unbekannt ist, von dem aber selbst ernsthaft zu nehmende Leute früherer Zeiten glaubten, daß es vom Himmel gefallen sei, und es deshalb *Meteorpapier* genannt haben.

[In a time in which, on the one hand, paper is in extremely short supply and, on the other, nearly all the money in circulation is in the form of paper banknotes, and in a time in which, because of lack of other raw materials, we manufacture our linen, clothes, blankets, curtains, and even binding rope from paper, it may be appropriate to draw some attention to a special, virtually unknown type of paper, about which in former times even serious people believed that it had fallen from the skies, and therefore had called it meteor paper.][1]

These intriguing sentences were written just after the end of World War I by Dr. Bruno Schröder from Breslau (currently Wrocław, Poland), in a paper entitled "Über Meteorpapier" (Schöder, 1919). Sightings of "Meteorpapier" falling from heaven had first been reported in 1639 and in 1686. Particularly, the latter event aroused considerable interest among contemporary scientists, and many theories were proposed in the course of time on the origin of this paper-like material. Only in 1838 was the enigma of the true nature of the "Meteorpapier" solved; thanks to the observations of the famous botanist Christian Gottfried Ehrenberg (1795–1876) (Fig. 1), who is also remembered as a pioneer of bacterial taxonomy (Ehrenberg, 1838a, b, 1839). He unequivocally demonstrated that the paper-like material originated from desiccated microbial mats that develop on the shores of certain lakes and on flooded grasslands.

[1] Translations from the writings of Schröder, Kersten, Ehrenberg, Cohn and others are by the author.

Figure 1. Portrait gallery of some of the scientists mentioned in the text who had been involved in the study of "Meteorpapier": Simon Pauli the Younger (1603–1680), Ernst Florens Friedrich Chladni (1756–1827), Christian Gottfried Daniel Nees von Esenbeck (1776–1858), Jöns Jakob Berzelius (1779–1848), Freiherr Christian Johann Dietrich Theodor von Grotthuß (1785–1822), Johannes Hieronymus Kniphof (1704–1763), Christian Gottfried Ehrenberg (1795–1876), Heinrich Robert Göppert (1800–1884), Ferdinand Cohn (1828–1898), and Friedrich August Rudolph Kolenati (1812–1864). Biographical data given in the text were derived in part from Schlegel (1999).

The "Meteorpapier" story, which was a popular topic in the scientific writings of the ninteenth century, was nicely summarized in Schröder's above-mentioned paper from 1919, on which much of the information presented here is based. The subject was only rarely mentioned in the more recent literature, a notable exception being the review by Stal (2000) on cyanobacterial mats and stromatolites.

This essay provides an overview of the literature on "Meteorpapier," showing how the concepts about its nature and origin have developed during the past three and a half centuries.

2. Early Reports on "Meteorpapier" and Theories on Its Origin

The first record of "Meteorpapier" probably dates from 1639, when a dense, white mass of paper-like material was found on the fields close to a lake in Norway. It had some resemblance to fine English linen or to Chinese paper. A sample was sent to Simon Pauli, professor of botany at the University of Rostock, but he did not succeed in elucidating its nature.

Far better known became a paper-like mass from Curland (southern Latvia). During a snowstorm in the afternoon of January 31, 1686, the area around a pond near the village of Rauden, north of Memel (currently Klaipėda, Lithuania) became covered with a coal-black, leaf-like, or paper-like substance that had not been there in the morning. Some people had actually seen it falling flake-wise from the air. The rumor spread quickly, and many came to witness this enigmatic phenomenon. Some pieces had the size of a table, and in some places stacks as thick as a finger had accumulated. When wet, the material had a bad smell like rotten seaweed, but in a dry state it lacked any smell. When torn, it appeared to consist of fibrous material, like blotting paper or printing paper. Berzelius (1822), based on earlier published reports, noted that people did not dare to touch the material, fearing that it was a product of witchcraft, but that a poor beggar who was on his way to a nearby estate lifted a piece to show it as a curiosity.

The scientific world at the time became highly excited about this "paper snow." Dr. Johann Georg Weygand, physician in Goldingen (the present-day Kuldīga) in Curland, claimed that it undoubtedly was real paper, washed ashore from a ship wrecked in the Baltic Sea, and having rotten for some time in bales among seaweed on the coast, causing its color and smell. After drying, the material could then have been carried through the air over a long distance by the north-eastern storm. An altogether different, and much more exciting, opinion was expressed by Dr. Philipp Jakob Hartmann, professor of medicine in Königsberg (currently Krolewiec, Poland), who in 1689 published a book entitled "Exercitatio generatione mineralium, vegetabilium et animalium in aëre" [Treatise on the generation of minerals, plants and animals in the air] (Hartmann, 1689). He claimed that the phenomenon had been caused by the activity of a meteor, as the paper-like mass had fallen from the skies in coherent pieces, which were later torn up by the storm. The physicist Ernst Florens Friedrich Chladni (1756–1827), in his 1819 essay about "fire meteors," tentatively classified the masses of paper fallen from heaven as derived from "soft meteors" (whatever that term may mean!). As late as 1825, Nees von Esenbeck, president of the Leopoldinisch-Karolinische Gesellschaft in Halle, considered the paper-like material from Curland as probable "aerophytes" or "plants from the air."

Chemical experts also became interested in the nature of the "Meteorpapier." Theodor von Grotthuß (1785–1822) performed in 1819 a chemical analysis of the Curland paper, a sample of which was present in the estate of his father. He detected three main components: "Kieselerde" (silica), "Kalkerde" (calcium carbonate), and "Bittererde" (magnesium oxide). In addition, he found traces of three components that at the time were considered characteristic of meteors, namely sulfur, nickel, and chromium. Von Grotthuß, therefore, concluded that the material undoubtedly had originated from a meteor. He sent some of the material to the famous chemist Jakob Berzelius in Stockholm to obtain confirmation of its nickel content. However, Berzelius did not detect any traces of nickel in the samples. On renewed analysis, von Grotthuß also failed to find nickel, and he admitted that he probably had mistakenly identified iron sulfide as nickel sulfide.

In the mean time, similar paper-like material had been found in other locations as well. Samples were kept in collections of curiosa from nature, maintained to be admired both by contemporaries and by future generations.

3. The Elucidation of the True Nature of the "Meteorpapier"

Already in the eighteenth century, some investigators began to suspect that the paper-like material may be a product of the plant world. Thus, Johannes Hieronymus Kniphof (1704–1763) wrote an essay entitled "Physikalische Untersuchung des Peltzes, welchen die Natur durch Fäulnis auf einigen Wiesen im Jahre 1752 hervorgebracht hat" [Physical investigation of the coating formed by nature by decay on some grasslands in 1752], and John Strange F.R.S. (1732–1799) wrote in 1764 that water plants, or microscopic filamentous algae ("Conferva" as Pliny had named them) had formed such a paper-like substance.

The true origin of the "Meteorpapier" was disclosed in 1838–1839. The 1839 volume of the "Annalen der Physik" contains two short publications, one by L.M. Kersten, which is followed by a paper by Christian Ehrenberg. Kersten had performed a chemical analysis of a material that had a striking similarity with leather, and that had been formed on grassland on the Drahthammer near Schwarzenberg in the Ore Mountains in Saxony (Kersten, 1839). Kersten described its origin as follows: "On the water that had flooded the grassland, a slimy green material was formed. After the water was slowly drained it settled on the grass, dried out, completely lost its color, and finally it could be removed in large pieces. This natural product resembles on its outer surface soft polished glove leather or smooth fine paper. It is somewhat shiny, soft to the touch, and has the strength of normal white printing paper. On its lower surface, which had been in contact with the water, it has a bright green color. It is still possible to distinguish green leaves from which the leather-like cover originated. A botanist could probably identify the species to which these belong." A detailed account of the chemical analysis of the material then follows, after which Kersten concludes: "The ash of the unknown substance mainly consists of silica and oxides of manganese and iron. The material itself, however, appears to be an aggregate of leaves, from which the chlorophyll as well as the other organic compounds have completely disappeared as a result of an organic process."

Ehrenberg added a postscript to Kersten's article in which he wrote: "Regarding the leather-like material from the Schwarzenberg meadow, microscopic examination clearly shows that it consists of *Conferva capillaris*, *Conferva punctalis*, and *Oscillatoria limosa* [for further information on the names of microorganisms mentioned and their modern equivalents, see Table 1]. Together, these form a dense mat, at the upper surface bleached by the sun, in which a few fallen leaves and blades of grass are incorporated. Dispersed between these microalgae, one finds numerous diatoms, in particular *Fragillaria* species and *Meridion vernale*. I have observed 16 different diatom species belonging to six genera, and in addition three more soft-shelled protists, as well as desiccated specimens of "*Anguillula fluvatilis*" (a nematode), a total of 20 different

Table 1. Names of microorganisms mentioned in the cited documents relating to "Meteorpapier," and their modern equivalents, if applicable. Nomenclature information was derived in part from Geitler (1932) for cyanobacteria and from Fritsch (1956) and Chapman and Chapman (1973) for eukaryotic algae.

	Genus and species	Current name
Cyanobacteria		
	Oscillatoria limosa	
	Lyngbya turfosa	?
	Lyngbya sudetica	*Lyngbya sudetica* (Nave) Kirchner ex Hansgirg, 1892
	Nostoc	
Chlorophyceae		
	Conferva capillaris	*Conferva capillaris* **(**Kützing) Rabenhorst 1847 is an illegitimate name; it is currently regarded as a synonym of *Chaetomorpha ligustica* (Kützing)
	Conferva punctalis	An illegitimate name; current equivalent unknown
	Conferva vesicata Agardh	*Oedogonium vesiculatum* Link
	Conferva crispata	*Conferva crispata* Roth 1979 is an illegitimate name. The name is currently regarded as a synonym of *Cladophora glomerata* var. *crassior* (C. Agardh) van den Hoek
	Cladophora fracta var. *viadrina*	*Cladophora fracta* var. *viadrina* (Kützing) Kirchner 1878 is currently regarded as a synonym of *Cladophora fracta* (O.F. Müller ex Vahl) Kützing
	Microspora floccosa	*Microspora floccosa* (Vaucher) Thuret
	Rhizoclonium hieroglyphicum	Rhizoclonium hieroglyphicum (C. Agardh) Kützing
	Cladophora crispa	= ?? *Cladophora crispata* (Roth.) Kützing = ?? *Cladophora glomerata*
	Binuclearia	
	Spheroplea annulina	*Spheroplea annulina* (Roth.) Agardh
Bacillariophyceae		
	Fragillaria	
	Meridion vernale	
Gramineae		
	Glyceria fluitans	(Manna grass)
	Glyceria spectabilis	*Glyceria maxima* (Reed sweet-grass)
Animals		
	Anguillula fluvatilis	Probably a nematode
	Daphnia pulex	The common water flea
	Planorbis	

species." Ehrenberg had also obtained samples of the same material earlier examined by Grotthuß and Berzelius. He did not recognize any recognizable small seeds in these fragments, but he found it to consist of the same microalgae as well as the same types of protists. A piece of yellowish material resembling Chinese silk paper sent by Berzelius, which had been formed (whether recently or in earlier times was not mentioned) on the dried-out shore of a Swedish lake, consisted entirely of yet another

freshwater microalga, *Oedogonium vesiculatum* Link (*Conferva vesicata* Agardh), between which many pollen of spruce trees as well as protists were observed.

Ehrenberg's own article on the true nature of the "Meteorpapier" deserves to be cited in full here:

> XX. Ueber das im Jahre 1686 in Curland vom Himmel gefallene Meterorpapier;
> Von C. G. Ehrenberg.
> Aus den Berichten der K. Preuß. Academie.
>
> Am 31. Januar 1686 fiel beim Dorfe *Rauden* in Curland mit heftigem Schneegestöber eine große Masse einer papierartigen schwarzen Substanz aus der Luft; man sah sie fallen, und fand sie nach Tische an Orten, wo die beschäftigten Arbeiter vor Tische nichts Aehnliches gesehen hatten. Diese 1686 und 1688 umständlich beschriebene und abgebildete Meteorsubstanz was neuerlich von Hrn. v. Grotthuß, nach einer chemischen Analyse, wiederholt für Meteormasse gehalten worden, den angegebenen Nickelgehalt hatte aber Hr. v. Berzelius, der sie ebenfalls analysirte, nicht erkannt, und Hr. v. Grotthuß widerrief ihn dann selbst. In Cladni's Werke über die Meteore ist sie aufgeführt und auch in Nees von Esenbeck's reichem Nachtrage, in R. Brown's bot. Schriften ist sie als Aërophyt angemerkt. Hr. E. untersuchte diese Substanz, von welcher etwas auf dem Königlichen Mineraliencabinet (auch in Chladni's Sammlung) befindlich ist, mikroskopisch. Sie besteht danach völlig deutlich aus dicht verfilzter *Conferva crispata*, Spuren eines *Nostoc* und aus bis 29 wohlerhaltenen Infusorien-Arten, von denen nur 3 in dem größeren Infusorien-Werke noch nicht erwähnt, aber wohl auch schon bei Berlin lebend vorgekommen sind, überdieß auch aus Schaalen der *Daphnia Pulex*. Von den 29 Infusorien-Arten sind nur 8 kieselschaalige, die übrigen weich oder mit häutigem Panzer. Mehrere der ausgezeichnetsten sehr seltenen Bacillarien sind darin häu. Diese Infusorien haben sich nun 152 Jahre erhalten. Die Masse kann durch Sturm aus einer curländischen Niederung abgehoben und nur weggeführt, aber auch aus einer sehr fernen Gegend gekommen seyn, da selbst aus dem Mexicanischen Amerka Hr. Carl Ehrenberg die bei Berlin lebenden Formen eingesandt hat. In der Substanz liegende fremde Saamen, Baumblätter und andere dergl. Dinge würden, bei weiterer Untersuchung größere Mengen, solche Zweifel entscheiden. Die vielen inländischen Infusorien und die Schaalen der gemeinen *Daphnia Pulex* scheinen dafür zu sprechen, daß ihr Vaterland weder die Atmosphäre noch Amerika, sondern Ostpreußen oder Curland war. – Die Substanz und die Abblidungen aller Bestandtheile derselben wurden vorgezeigt.
>
> XX. On the meteor paper that fell from heaven in Curland in the year 1686
> By C. G. Ehrenberg
> From the proceedings of the Royal Prussian Academy
>
> On January 31, 1686, a large amount of a paper-like black substance fell from the skies in the village of Rauden in Curland during a heavy snowstorm. People saw it falling, and workers returning from their lunch found it on places where they had not seen anything of the kind before they had left. This material from heaven, which had been extensively described and illustrated in 1686 and in 1688, was again attributed to meteors by Mr. von Grotthuß, based on chemical analysis. However, Mr. von Berzelius, who also had analyzed the substance, did not detect

> the indicated content of nickel, and this was subsequently withdrawn by Mr. von Grotthuß himself. The material is mentioned in Chladni's works about meteors, and also in Nees von Esenbeck's rich legacy; in the botanical works of R. Brown, it is indicated as an aerophyt. Mr. E[hrenberg] microscopically investigated this material, some of which is present in the Royal Cabinet of Minerals, as well as in Chladni's collection. According to the analysis, it was obvious that it completely consisted of *Conferva crispata* forming a dense mat, traces of a *Nostoc*, and of up to 29 well-preserved species of protists, only three of which have not been previously recorded in the handbooks on protists, and in addition of shells of *Daphnia pulex*. Among the 29 types of protists, only 8 had a siliceous shell, the others are soft-walled or have a skin-like shell. Several notable types of very rare diatom species occur frequently. These protists have been preserved for 152 years. It is possible that the material had been lifted from lowlands in Curland, but it may as well have been transported from a more remote area: Mr. Carl Ehrenberg even has sent forms from Mexico that occur near Berlin. When examining larger quantities, one can identify without any doubt seeds, leaves from trees, and similar objects. The abundance of local protists and the shells of the common *Daphnia pulex* may indicate its origin neither from the atmosphere or America, but from East-Prussia or Curland. The material and illustrations of all its components were presented [at the meeting].

To get hold of additional samples of similar material for a comparative study, Ehrenberg approached the botanist Prof. Heinrich Göppert (1800–1884) in Breslau. The latter had found in the St. Bernhardin library in Breslau four large sheets of a paper-like material, 34 × 2–4 ft in size. It was known as "Oderhaut" ["Skin from the Oder"], and Göppert assumed that it had originated during massive floods caused by the river Oder in 1736. The events that led to its formation had been described by Johann Christian Kundmann (1736), a physician and collector from Breslau (1684–1751), in his book "Rariora naturae et artis" [Curiosites from nature and art]. After the Oder had inundated large areas in Silesia, a tough layer was observed on the grasslands after the water had receded. On being desiccated, it became strong as leather and it could be torn only with difficulty. It was white or yellowish to red-brown in color, and its upper surface was perfectly flat, so that one could write on it. On the lower side, however, it felt like silk. In color and strength, it resembled gray wrapping paper. The upper firm layer could easily be separated from the lower, less dense mat, which was brownish to greenish in color. At the lower side, numerous leaves and roots of grasses (*Glyceria fluitans* and *G. spectabilis*) could be seen, as well as shells of water snails (*Planorbis*). Göppert found the substance to consist almost exclusively of the filamentous green alga *Cladophora fracta* var. *viadrina* together with many small aquatic animals and insects. Ehrenberg detected 19 more species in this material.

In June 1849, Göppert and his student Ferdinand Cohn (1828–1898) made a botanical excursion east of Breslau to the so-called Morgenauer meadow, a humid land tongue between the Oder and the mouth of the Ohle. Flooding of these rivers had caused the formation on pools and puddles in the lower areas, and these

became covered with a dense green floating mat. At the edge around the pools, a dry, yellowish-green or gray, more or less densely woven skin-like material was found on the soil. Parts of it were smooth and thick like course wrapping paper, other parts more loose like sack cloth, linen, or tow. Near the water, it merged with a floating mat of microalgae, and occasionally it was pushed up, perforated, and disrupted by the grass around the pools. Göppert and Cohn immediately remembered the algal mat material examined by Ehrenberg. They concluded that a number of biological and physical conditions must be fulfilled to produce the phenomenon: dense growth of certain types of filamentous algae when the area is flooded, a rapid retreat of the flood water, and a soil that does not retain humidity for long periods but enables desiccation of the algal mat by the heat of the sun before it is degraded. Microscopical analysis showed *Cladophora fracta* var. *vadrina* to be the main component. On and between its filaments lived numerous diatoms, belonging to almost the same species found by Ehrenberg in the "Oderhaut" from St. Bernhardin near Breslau, which had been collected more than a 100 years earlier. Göppert and Cohn commented that these organisms, thus far considered cosmopolitan, may well have their own characteristic geographical distribution, so that it should be possible to compile a flora and a fauna of different countries not only of higher plants and animals, but also of microorganisms. Later in his life did Ferdinand Cohn indeed write such a document for algae and other lower plants, published in 1878 under the title "Kryptogamen-Flora von Schlesien" (Cohn, 1878). In the introduction to this book, he mentioned Göppert's earlier work and noted that the sample collected a century earlier by Kundmann, preserved in the St. Bernardhin library and examined by Göppert in 1840, had been the source of the earliest documented microalgae from Silesia.

There are additional reports from the nineteenth century on findings of similar paper-like algal mats. In October 1854, Ferdinand Cohn found such a dried algal mat on a potato field near Breslau that had previously been inundated by flooding of the Oder. This dark red-colored algal mat was formed by filaments of *Spheroplea annulina*. Similar mats of the same alga had been found near Berlin by Ehrenberg and near Bremen by Ludolph Christian Treviranus (1779–1864). Friedrich August Rudolph Kolenati (1812–1864) from Brno recorded such a thick of reddish to bluish or dark-green layer formed by the cyanobacterium *Lyngbya sudetica* at the Mitteloppa spring on the Leiterberg in the Moravian slope of the Sudeten mountains. Anton Hansgirg (1854–1917) mentioned in his flora of the algae of Bohemia of 1886 mats of *Cladospora fracta* var. *viadrina* at the shore of ponds near Leitmeritz and Lobositz (Litomerice and Lovosice in the Czech Republic). G. von Istvanffy published in 1890 a document in Hungarian about "Meteorpapier" from three additional locations: a *Cladophora fracta* var. *viadrina* mat on river banks near Budapest, similar growth of blue-green paper-like covers of *Lyngbya turfosa* on the banks of Lake Czoba in de High Tatras, and a mat consisting of sterile filaments of *Oedogonium* and of *Microspora floccosa* from peat bogs in Westphalia. On the shore of the Neusiedlersee (Austria), Siegfried

Stockmayer (1868–1938) found such material formed by *Rhizoclonium hieroglyphicum* and *Cladophora crispa*. Then, there is a report on "Meteorpapier"-like material formed on the banks of the Danube near Vienna, allegedly formed by the cyanobacterium *Microcoleus chthonoplastes* (Stockmayer, 1893). [Possibly a misidentification, as this species is not commonly found in freshwater environments; for new insights into the taxonomy of the genus *Microcoleus* see Siegesmund et al., 2008.] Finally, Schöder (1919) repeatedly found "Meteorpapier" on fenland, first in 1900 at the Lanfstuhlmoor near Kaiserslautern in de Rheinpfalz and in 1917 on the Seefeldern near Reinerz (Glatz [Klodzko], Poland) on the Iserwiese in Silesia. In this material, he identified filaments of *Oedogonium*, *Microspora*, *Binuclearia*, and several Zygnemaceae.

4. Final Comments

Although largely forgotten today, it is fascinating to follow the ideas and theories that have existed since the first records of "paper that fell from the skies" in the seventeenth century on the true nature of this material. Although some of the best-known natural scientists of the seventeenth and the eighteenth centuries have occupied themselves with the study of the "Meteorpapier," the true nature of the material was discovered only 200 years after the first record of its sighting in Norway.

This essay opened with the intriguing question by Schöder (1919) whether "Meteorpapier" could be considered as a possible substitute for paper in a time in which the real product was in short supply. He himself gave the answer in the last paragraph of his article:

> So hat sich mit der Erforschung des durch Grün- und Blaualgen gebildeten Meteorpapieres, das sowohl in der Ebene wie auf Bergeshöhen an Flußufern, Teiche und Seen, wie auf Hochmooren in vielerlei Farbentönen vorkommt, die Wissenschaft durch fast drei Jahrhunderte bis in die heutige Zeit mit mehr oder weniger Erfolg beschäftigt, nicht nur die Botanik, sondern auch die Physik, die Chemie und die Geologie. Man gelangte zu den allgemeinen Ergebnis, daß dadurch die Wichtigkeit der mikroskopischen Analyse zuerst zu ihrem Rechte kam, daß die Grundlage zu einer Flora und Fauna niederer Organismen gelegt und die Bildung der Torflachen auf Mooren erklärt wurde, und es ist nur zu bedauern, daß das Meteorpapier unserer heutigen Papiernot nicht abzuhelfen vermag.
>
> [For nearly 300 years until the present time has science – botany as well as physics, chemistry, and geology – thus occupied itself more or less successfully with the examination of the "Meteorpapier." It is formed by green algae and cyanobacteria, and is found in plains as well as high in the mountains, on the banks of rivers, ponds, and lakes as well as on fenland in many different shades of color. The general results were that microscopical analysis first got the importance it deserves, that the basis has been established for a flora and fauna of lower organisms, and that the formation of the bog pools on fens was explained. It is only to be regretted that "Meteorpapier" will not be able to relieve our current scarcity of paper.]

5. References[2]

Berzelius, J. (1822) *Jahres-Bericht über die Fortschritte der physischen Wissenschaften.* Von Jacob Berzelius. Aus dem Schwedischen übersezt von G. G. Gmelin. Erster Jahrgang. Tübingen, bei Heinrich Laupp.

Chapman, V.J. and Chapman, D.J. (1973) *The Algae*, 2nd ed. Macmillan, London.

Cohn, F. (1878) *Kryptogamen-Flora von Schlesien.* Im Namen der Schlesischen Gesellschaft für vaterländische Cultur herausgegeben von Prof. Dr. Ferdinand Cohn. Zweiter Band, Erste Hälfte. Algen. Bearbeitet von Dr. Oskar Kirchner. J.U. Kern's Verlag (Max Müller), Breslau.

Ehrenberg, C.G. (1838a) *Mikroskopische Analyse des curlandischen Meteorpapiers von 1686 und Erlauterung als ein Produkt jetzt lebender Conferven und Infusorien.* Ein Vortrag in der Akademie der Wissenschaften zu Berlin von 6 December 1838. Berlin, 1839.

Ehrenberg, C.G. (1838b) Ueber das im Jahre 1868 in Curland vom Himmel gefallene Meteorpapier und über dessen Zusammensetzung aus Conferven und Infusorien. Abhandlungen der Königlichen Akademie der Wissenschaften Berlin, Physikalische Klasse 44–60.

Ehrenberg, C.G. (1839) Ueber das im Jahre 1686 in Curland vom Himmel gefallene Meteorpapier. Annalen der Physik **122**: 187–188.

Fritsch, F.E. (1956) *The Structure and Reproduction of the Algae*, Vol. I. Cambridge University Press, Cambridge.

Geitler, L. (1932) *Cyanophyceae,* In: *Dr. L. Rabenhorst's Kryptogamen-Flora von Deutschland, Österreich und der Schweiz*, Vol. XIV. Leipzig: Akademische Verlag; reprint (1985). Koeltz Scientific Books, Koenigstein.

Hartmann, P.J. (1689) *Exercitatio de generatione mineralium, vegetabilium et animalium in aëre, occasione annonae et telae coelitus delapsorum, anno 1686 in Curonia.* Ephemeridibus Naturae Curiosorum. Nuremberg.

Kersten, L.M. (1839) Ueber eine auf Wiesen gebildete lederartige Substanz. Aus einem Schreiben des Hrn. Prof. L.M. Kersten. Annalen der Physik **11**: 183–186.

Kundmann, J.C. (1736) *Rariora naturae et artis, item in re medica, oder Seltenheiten der Natur und Kunst des Kundmannischen Naturalien-Cabinetts, wie auch in der Artzeney-Wissenschafft I. Examen fossilium & lapidum quorundam rariorum. II. Memorabilia naturae & artis. III. Observationes in re medica singulares.* Breslau and Leipzig, Michael Hubert, 1737.

Schlegel, H.G. (1999) *Geschichte der Mikrobiologie.* Deutsche Akademie der Naturforscher Leopoldina, Halle.

Schöder, B. (1919) Über Meteorpapier. Die Naturwissenschaften **7**: 605–608.

Siegesmund, M.A., Johansen, J.R., Karsten, U. and Friedl, T. (2008) *Coleofasciculus* gen. nov. (Cyanobacteria): morphological and molecular criteria for revision of the genus *Microcoleus* Gomont. J. Phycol. **44**: 1572–1585.

Stal, L.J. (2000) Cyanobacterial mats and stromatolites, In: B.A. Whitton and M. Potts (eds.) *Ecology of Cyanobacteria: Their Diversity in Time and Space*. Kluwer, Dordrecht, pp. 61–120.

Stockmayer, S. (1893) Ueber die Bildung des Meteorpapiers und eine aus *Microcoleus chthonoplastes* zusammengesetzte Algenhaut aus dem Inundationsgebiete der Donau bei Wien. Verhandlungen der Kaiserlichen-Königlichen Botanischen Gesellschaft **43** (2): 28–30.*

[2] Documents to which the author did not have access during the writing of this essay are marked with an asterisk.

http://www.springer.com/978-90-481-3798-5

Microbial Mats
Modern and Ancient Microorganisms in Stratified Systems
Seckbach, J.; Oren, A. (Eds.)
2010, XXVI, 606 p., Hardcover
ISBN: 978-90-481-3798-5