Photography of plant fossils—New techniques, old tricks

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Review papers

Photography of plant fossils—New techniques, old tricks

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ABSTRACT

Photographic documentation is crucial for palaeobotanical studies when dealing with fossil material of any sort. However, many palaeobotanical objects are notoriously difficult to photograph due to the lack of contrast, the lack of three-dimensional relief of the objects or a combination of both. This contribution summarises a number of very simple methods and techniques to improve the quality of images for palaeobotanical and palynological publications. We primarily focus on the exposure, because this is the most essential step of the process. The quality of images can easily be improved without using costly equipment.

Contents

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1. Introduction

Photographic documentation is crucial for palaeobotanical studies when dealing with fossil material of any sort. Proper photographic illustration ideally forms the least subjective means of presenting the 'data', i.e., the fossils, and should thus be as well-prepared and effective as possible. When illustrating fossils, the same care should be taken as when describing and interpreting them. Last but not least, many plant fossils have a certain aesthetic value, and well-prepared illustrations of such fossils may simply impart the fascination of the subject.

However, many palaeobotanical objects are notoriously difficult to photograph due to the lack of contrast, the lack of three-dimensional relief or a combination of both. Black adpressions on a black sediment matrix are not exceptional. In other cases, contrasts and relief are very strong, making photographic documentation equally difficult.

The introduction of digital photography was a revolution that has made photography much easier. In many cases, the change to digital photography has made the position of a professional photographer redundant, because the scientist can now make her or his own images; in microphotography, it is merely a matter of pressing the button. However, many principles from the traditional wet negative/positive process have not changed, particularly with regard to the exposure. Several accounts on photographing (plant) fossils have been published (e.g., Benson, 1965; Douglas, 1965; Rasetti, 1965; Samuelsson, 1965; Whittington, 1965; Schaarschmidt, 1973; Howell, 1977; Barthel, 1996; Rowe, 1999). These all deal with the traditional wet-chemical processing and black-and-white prints. Although exposure techniques are essentially similar for digital colour images, there are some differences. Moreover, several techniques to improve the quality of the photographs seem to have been forgotten; others have been developed in recent years. This contribution summarises several very simple methods to improve the quality of photographs. We primarily focus on the exposure, because this is the most essential step. In the old days, only a good negative could give a good print. Similarly, a poor digital image can, despite all the possibilities of advanced image processing software, never yield a good print. We do not discuss digital image processing in detail, because there are many good books on this subject and several good contributions on special applications in palaeontology. However, images should basically remain unaltered; only cropping and adjustments of brightness and contrast should be acceptable.

None of the methods presented and discussed in the next paragraphs is really new. Some have been applied for many decades, either in palaeontology or in other specialised fields such as forensic studies (e.g., Staggs, 2005). Nevertheless, the positive reactions on a recent congress presentation on this subject have encouraged us to compile this methodological review. Too often, plates showing technical problems are encountered, especially since the introduction of digital photography. Most problems could easily have been avoided without using costly equipment.

2. Historical account

2.1. Early photography

Photography has a long history and its significance for scientific documentation was recognised almost instantaneously. Nevertheless, it would take some time until photographic documentation became the standard in scientific publications. The oldest still surviving photograph was taken in 1826 by the French inventor Joseph Nicéphore Niépce (1765–1833). In 1835 the French painter and inventor Louis Jacques Mandé Daguerre (1787–1851) invented the daguerreotype for which he received a patent in 1839. Daguerreotypes are direct positives fixed on silver-plated copper plates. They show much detail but require very long exposure times. In 1839, the English soldier and geologist Levett Landon Boscawen Ibbetson (1799–1869) developed a method of taking lithographic impressions, so-called electrotypes, from daguerreotypes. One of his oldest published illustrations using his method shows a group of ammonoids.

Although daguerreotypes were very popular in the middle of the 19th century, they had limited value for scientific purposes because each image was unique and reproduction was not possible. The invention of the negative/positive process in 1834 by the English inventor and photo pioneer William Henry Fox Talbot (1800–1877) enabled making several prints from a single negative, i.e., to reproduce a single exposure many times. However, Fox Talbot, who patented the method in 1841, originally used paper negatives for his so-called salt prints. Although these prints already show considerable detail, they did not equal the sharpness of daguerreotypes. The introduction of glass negatives (1839) by the English mathematician, astronomer, chemist, and experimental photographer/inventor John Frederick William Herschel (1792–1871) and the introduction of the wet collodion process in 1851 by the English sculptor and photo pioneer Frederick Scott Archer (1813–1857) finally made photography widely applicable. These processes were much cheaper and faster than the older procedures and gave excellent results. Nevertheless, the wet plates had to be prepared immediately before the exposure was made and developed instantaneously, which required a suitable dark room on the spot. The negative/positive method was revolutionised in 1864 by the English photographers William Blanchard Bolton (1848–1899) and Benjamin Jones Sayce (1839–1895) who introduced the dry collodion emulsion, making the immediate vicinity of a dark room for direct processing no longer necessary. The English photographer and physician Richard Leach Maddox (1816–1902) finally introduced the gelatine emulsion (1871) that is still used today.

2.2. Photography and (plant) fossils

The applicability of photography for documenting scientific studies was immediately recognised. As early as 1839, Fox Talbot made salt prints of diatoms and cross sections through plant stems. The oldest daguerreotype showing the anatomy of a plant stem in which individual cells are well visible was made in 1840 by the German physicist and mathematician Andreas von Ettingshausen (1796–1878) who held a chair in physics at the University of Vienna. His son Constantin von Ettingshausen (1826–1897) was a well-known botanist and palaeobotanist who published numerous natural prints of skeletonised leaves between 1855 and 1873. In 1851, the French photographer and inventor Auguste Adolphe Bertsch (1813–1871) demonstrated high-quality prints of photomicrographs and a modified microscope with an attached camera at the Academy of Sciences in Paris. Between 1853 and 1857, he made a series of superb photomicrographs showing—amongst others—algae, diatoms, and

plant cuticles; his photomicrograph of a thin section of fossil wood, dated 1857, is probably the oldest, surviving photographic print of a plant fossil.

The first scientific publication containing real photographs printed from negatives was published in 1853 by the French assistant naturalist and photographer Louis Rousseau (1811–1874) and the well-known painter and lithographer Achille Devéria (1800–1857). Their booklet consists of ten lithographed and six photo plates of animal specimens from the collection of the Museum d'Histoire Naturelle in Paris. The first true photograph of a fossil was probably published by John Collins Warren (1778–1856), founder of the New England Journal of Medicine and Surgery. In 1854, Warren, who was already familiar with the use of photography in medicine, and the geologist and Amherst College professor Edward Hitchcock (1793–1864) published an account on the fossil footprints in the Connecticut River with a true photographic print on the frontispiece. For further information on the early applications of photography in palaeontology and on early microphotography we refer to Davidson (2008) and Keller (2008) respectively.

Abramo Bartolommeo Massalongo (1824–1860) from Verona, Italy, who is most famous for his work on modern lichens, was the first palaeobotanist who recognised the importance of documenting plant fossils photograpically. In 1859, he published a monograph on the fossil flora and fauna of the regions around Verona and Vicenza (Fig. 1), illustrated with 40 photographic plates of plant and animal fossils made by the German photographer Maurizio (Moritz) Lotze (1809–1890), who had opened a photo studio in Verona in 1852. Thirty-five photographs depict fossil plants, two from the Jurassic (Pliensbachian) Oolithic Limestone near Rotzo (Fig. 2), nine from the Oligocene of Chiavon/Salcedo, and the rest from the famous Eocene Monte Bolca fossil lagerstätte. These are the earliest published photographs of fossil plants. In his introduction Massalongo wrote several pages about the advantages of the revolutionary new developments in photography and their significance for science. When Massalongo and Lotze prepared their monograph, they were apparently unaware of Rousseau and Devéria's work as is clear from a footnote that is added on the last page. The earliest photographs of plant microfossils were published by Paulus Friedrich Reinsch (1836–1914), a German botanist whose studies mainly dealt with algae but who also studied the organic constituents and microstructure of coal (Reinsch, 1881). His monograph on the microflora of the Moscow brown coal and the Zwickau bituminous coal (Reinsch, 1884; Fig. 3), which is generally regarded as one of the earliest publications on palaeopalynology, contains two plates with photographs of spores, cuticles, plant tissues, algae and fungi from the upper Visean of the Moscow area (Fig. 4). These photographs were made by Georg Daßler (1836–1919), a photographer and lithographer from Erlangen. Like in Rousseau and Devéria's booklet, in Warren's publication, and in Massalongo's monograph, these illustrations are individual photographic prints that were tipped in.

Since the mid-19th century inventors in different countries experimented successfully with various methods to print photographs showing the full tonal range. One approach was transferring the photographic image to lithographic, metal (usually copper or zinc), or glass plates by repeated etching procedures. The collotype was developed in 1868 in Germany. Collotypes show very fine details and a whole scale of grey tones, and can be reproduced in large quantities. A noteworthy example of an early monograph largely illustrated with printed photographic plates (collotypes or "Zincotypen") is Dionysus Stur's (1827–1893) "*Die Carbon-Flora der Schatzlarer Schichten*". This monumental monograph appeared in two volumes (1885, 1887) with many lithographic plates and a total of not less than 91 double-paged photographic plates, mostly of excellent quality. Interestingly, in a remark added to one of the plate captions, Stur mentions that several photographers tried to photograph the specimen but that they faced considerable difficulties because of the poor contrast between the fossil and the matrix.

The invention of the halftone printing process was another giant step forward. The principle of halftone printing is based on the use of a screen breaking up the image into variously sized dots that are printed on a contrasting background. Although for black-and-white only one colour of ink is used (black on a white background), optical illusion, caused by the differences in size and spacing of the black dots, determines what we see, including grey tones. This commercially very successful method was patented in 1882 by the German engraver Georg Meisenbach (1834–1912). Modern printing techniques are still based on the same principle; for colour printing several screens are used in combination with four colours (i.e. Cyan, Yellow, Magenta and blacK; usually abbreviated as CYMK).

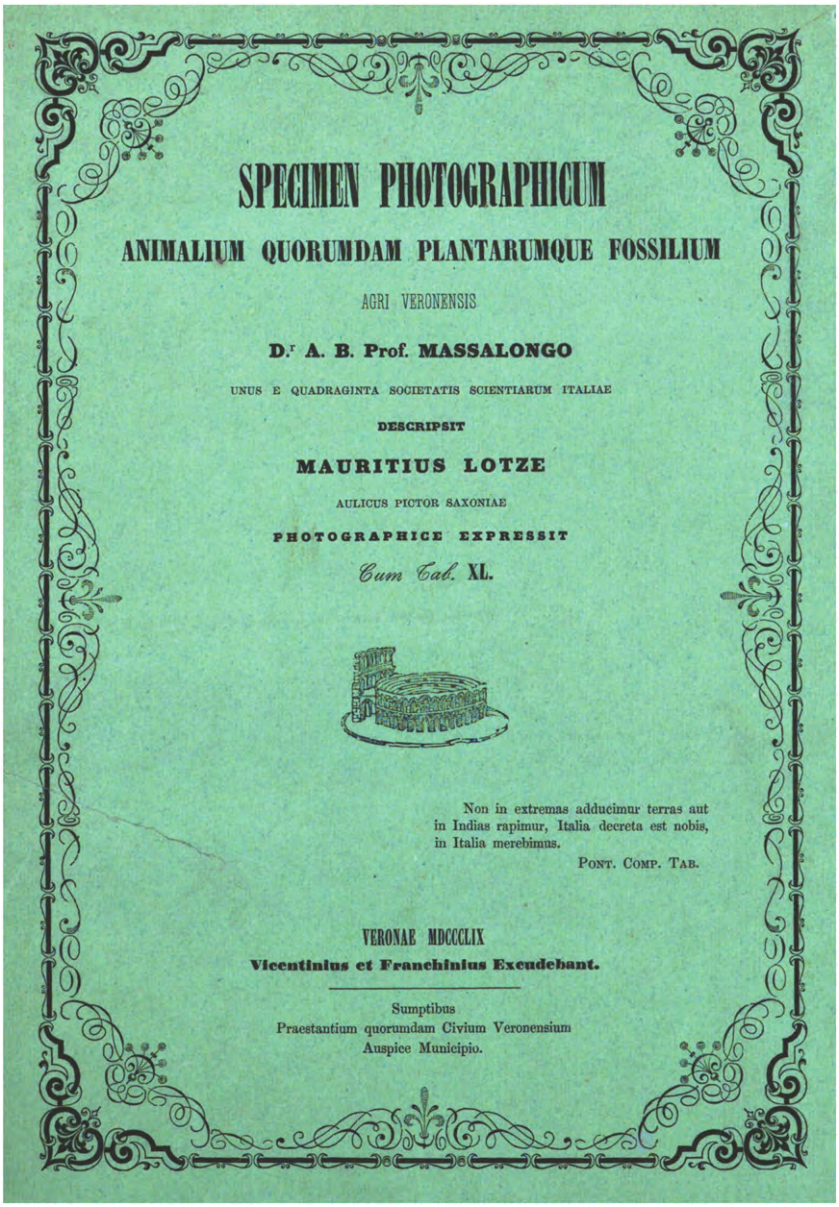
Around the turn of the century, photographic documentation gradually replaced lithographic illustration in palaeobotany. The quality of many early photographs is superb due the use of natural daylight, the large negative format and the continuous improvement of photographic processes. These are some of the finest examples of photographic documentation of plant fossils and the quality of many of these images remains unsurpassed, even with the modern equipment that is available today. Glass negatives were still widely used in the first half of the 20th century, but they were gradually replaced by 120 roll film that was introduced in 1901 (6×6 or 6×9 cm negatives) and the smaller 35 mm film format (24×36 mm negatives) in 1925, which made photography even easier and reduced the size of the cameras.

2.3. Early colour illustrations

The use of colour for illustrating fossil plants dates back to 1820 when Kaspar Maria von Sternberg (1761–1838) published the first part of his seminal "*Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt*", which is illustrated with numerous hand-coloured engravings by more than a dozen different artists (Cleal et al., 2005). The first colour illustrations of fossil plant spores in a scientific publication that we are aware of were published by Elovski (1930) and Ergolskaia (1930) (Fig. 5). However, these are excellently printed, very realistic watercolour paintings of spores and coal thin sections that at first sight look like true photographs. Although the first colour photograph dates back to 1861, colour photography long remained out of reach because initially the only commercially available colour medium was the autochrome, a direct positive on glass that was invented in 1904 by the Lumière brothers and introduced on the market in 1907. In the mid-1930s autochrome transparencies were replaced by 35 mm diapositives. In the early 1960s Wilson published a paper with three colour plates with images of fossil spores and pollen (Wilson, 1962). Wilson used colour because this, in his opinion, shows much more detail. Only less than a decade ago, when offset printing was replaced by digital printing, colour photographs became a regular feature in scientific journals.

2.4. The digital revolution

The digital revolution in photography started in the late 1960s with the invention of the CCD and CMOS electronic image sensors that are still used today. The first digital single lens reflex (DSLR) camera appeared on the market in 1991; it cost a real fortune and featured a resolution of 1.3 megapixels, which was still far from satisfactory. Image quality greatly improved and prices dropped steadily with the introduction of several DSLR cameras during the late 1990s. Nowadays, just a little bit more than ten years and several generations of digital cameras later, the quality of digital images equals or even surpasses that of conventional prints from negatives. The advantages of digital photography are clear. The time-consuming and costly wet-chemical processing, developing negative film and printing photographs in a special darkroom is no longer required. Instead, images are immediately available and can easily be processed and mounted on


SPECIMEN PHOTOGRAPHICUM

ANIMALIUM QUORUMDAM PLANTARUMQUE FOSSILIUM

AGRI VERONENSIS

D.r A. B. Prof. MASSALONGO

UNUS E QUADRAGINTA SOCIETATIS SCIENTIARUM ITALIAE

DESCRIPSIT

MAURITIUS LOTZE

AULICUS PICTOR SAXONIAE

PHOTOGRAPHICE EXPRESSIT

Cum Tab. XL.

Non in extremas adducimur terras aut
in Indias rapimur, Italia decreta est nobis,
in Italia merebimus.

PONT. COMP. TAB.

VERONAE MDCCCLIX

Vicentinius et Franchinius Excudebant.

Sumptibus
Praestantium quorumdam Civium Veronensium
Auspice Municipio.

Fig. 1. Frontispiece of Massalongo (1859), the earliest publication with photographs of fossil plants.

plates using a computer. Chips can store much more images than conventional film without any costs for processing, and unsuitable exposures are easily deleted.

3. Photographing hand specimens

3.1. The equipment

Adequate equipment is a prerequisite for making good photographs. This does not necessarily mean expensive equipment. For photographing hand specimens we use a standard DSLR camera with a 50 or 60 mm macro lens. For overviews of larger specimens, a 35 mm lens is used. Cameras should have a sufficiently high resolution. DSLR cameras are preferred over compact cameras with a single, fixed zoom lens because of the better quality of the optics, and the better resolution resulting from the larger size and higher quality of the electronic image sensors. Moreover, it is often not possible to mount a polarising filter on a compact camera. Older lenses from the pre-digital era can still be used on DSLR camera bodies with special, but very reasonably priced adapters. However, all automatic functions will be lost. The weak point of digital cameras with changeable lenses is that dust and dirt can easily settle on the electronic image sensor when lenses are changed. The sensor matrices are extremely sensitive and should only be cleaned by a professional repair shop or by the manufacturer. This problem is also recognised by camera manufacturers who developed DSLR cameras with self-cleaning sensors. Nevertheless, you should be extremely careful and avoid any dust in the camera.

Because the amount of light that is available is usually low, the camera should be able to measure long exposure times. There is a whole variety of good DSLR cameras on the market, and nowadays a good one does not need to be very expensive. A DSLR camera in the middle of the price range will fulfil all your needs; ultra-high shutter speeds and fancy automatic programmes are superfluous for photographing fossils. However, it is very useful if the camera can be connected to a computer, which may then serve as an external control for camera settings (i.e. exposure time and diaphragm) and as remote release. This is particularly helpful when the camera is mounted on a

Fig. 2. An example of the photographic illustrations in Massalongo (1859, pl. 22), showing *Araucarites rotzanus*, a conifer from the Calcari Grigi di Noriglio (Pliensbachian, Lower Jurassic) of Rotzo, Sette Communi, Trentino, northern Italy.

tripod or repro stand. When using a DSLR camera with a live view function and video or HDMI port, a computer monitor can also serve as a live view image. A separate large, preferably glossy computer screen gives a much better view than the viewfinder on the camera display and is particularly helpful for focusing. However, be sure that the colours, brightness and contrast of the additional screen are adjusted correctly and identical to those of the camera display, and that they match the print. The camera should be mounted in a stable position, because long exposure times are often required. For photographing hand specimens, a stable repro stand with adjustable lamps on two sides is ideal (Fig. 6). The combination of a repro stand with an additional macro-focusing rail can be very helpful for fine adjustment. Use a cable release, a remote control, or the self-timer function to avoid camera shaking. We prefer the self-timer function, because then during the exposure both hands remain free for other things, e.g., for holding reflection boards and for 'dodging'. Specimens that are photographed should also be in a stable position and lie parallel to the plane of the objective lens or the back of the camera. The best solution is to place the fossil on a linen bag filled with sand. The specimen can then easily be adjusted and it lies very stable. Small objects can be mounted with plasticine modelling clay, which guarantees a stable horizontal position.

3.2. Lights

Good lighting makes or breaks the image. Most fossils are photographed using artificial light. For photographing hand specimens we work with two different light sources, (1) a set of two reflectors, each with two separately switchable daylight tube lights, and (2) four simple 60 W reflector lamps (conventional incandescent light bulbs with tungsten filaments), two at each side (Fig. 6). For details we use a 250 W cold-light (halogen) source with fibre optics.

Micro-PalaeoPhytologia

Formationis Carboniferae.

Iconographia et Dispositio Synoptica Plantularum microscopicarum omnium in venis Carbonis Formationis Carboniferae hucusque cognitarum,

eorumque illis proximorum corpusculorum natura vegetabilica non incerta, quae inveniuntur et in venis carbonis et in stratis Formationum infra supraque Carboniferam sequentium.

Auctor

Paulus F. Reinsch.

Volumen Primum.

Continens Trileteas et Stelideas.

Accedunt Tabulae Sexaginta novem.

Erlangae, Germania.
Redemptio Autoris et Apud Theodorum Krische Bibliopolam.

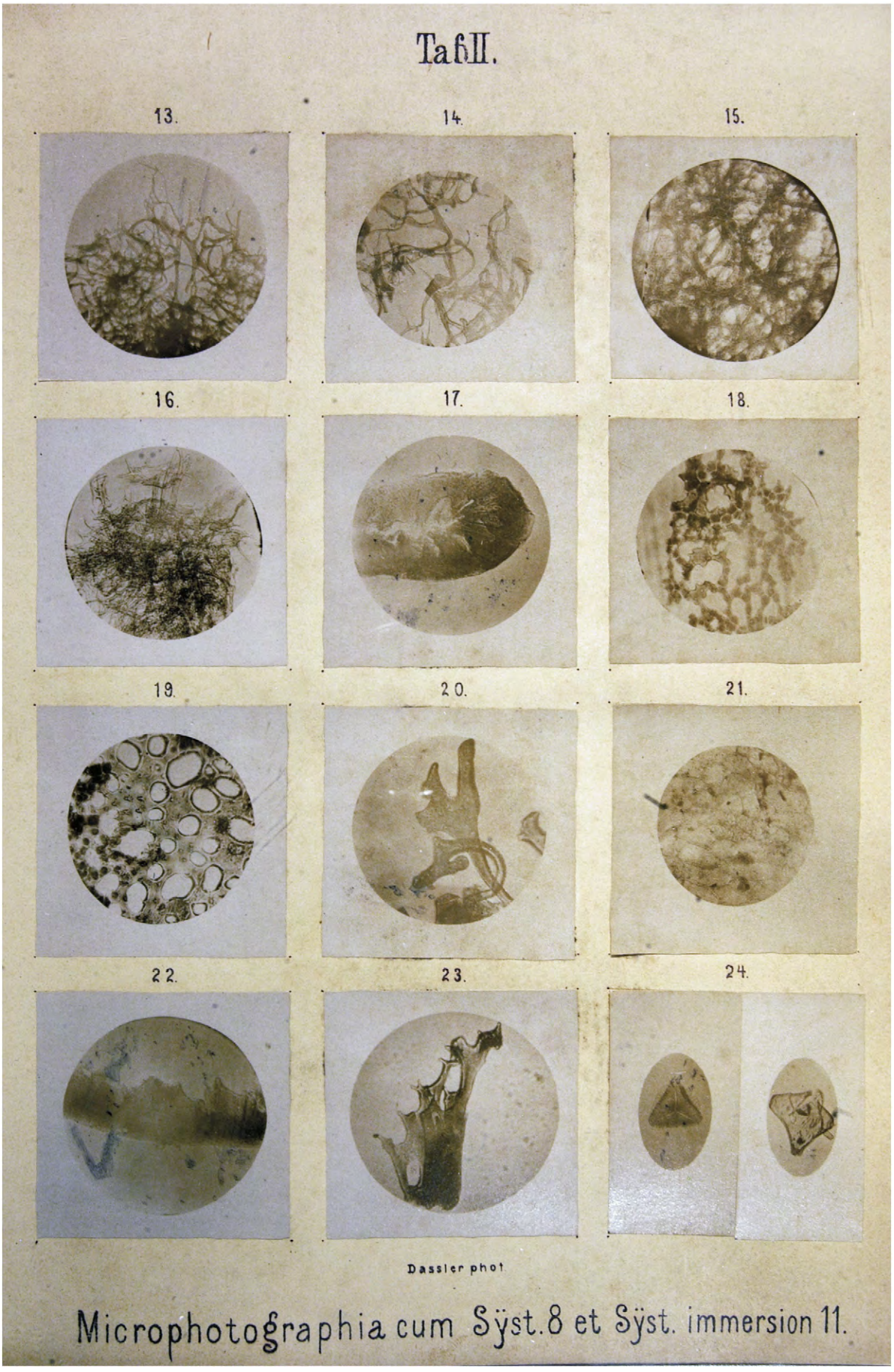
Londinii.
Apud Bernardum Quaritch Bibliopolam.
MDCCCLXXXIV.

Fig. 3. Frontispiece of Reinsch (1884), a monograph that is generally regarded as one of the very early palaeopalynological publications; this monumental monograph contains two photographic plates with 12 and 13 photographs respectively that are numbered from 1 to 24; plate II, 24 consists of two photographs (see Fig. 5).

Whatever light source you choose, lights should be freely positionable, not fixed. The lamps of classical repro stands like the still widely used Leitz Reprovit are fixed at 45°. This is the ideal position for copying illustrations from books and reproducing documents. However, this set up is far from ideal for photographing fossils, because the angle of the light beam determines whether the illusion of three-dimensional structure is visible or suppressed. Much better are repro stands with freely positionable lamps that can be switched and off separately. A good repro stand has lamps that can be positioned at any possible angle, from the same level as the fossil to perpendicular to it, and from close to the object to several decimetres away (Fig. 7). The more flexibility in positioning the light sources, the better it is.

We prefer working in a darkened room with black walls and no other lights than those used for lighting the specimen in order to avoid false light and reflections. The colour of the light reflected by an object depends on the colour temperature of the light source. Each light source has a particular colour temperature expressed in units of absolute temperature, Kelvin (K). Low colour temperatures below *c.* 3000 K as in traditional light bulbs result in warm, red to yellowish-white colours, whereas high colour temperatures above 5000 K, e.g.

Fig. 4. One of the two photographic plates published by Reinsch (1884, pl. 2) showing organic remains from the upper Visean Moscow brown coal. Fig. 24 shows *Diatomozonotriletes* (left) and the algal fossil *Mougeotia* (right).



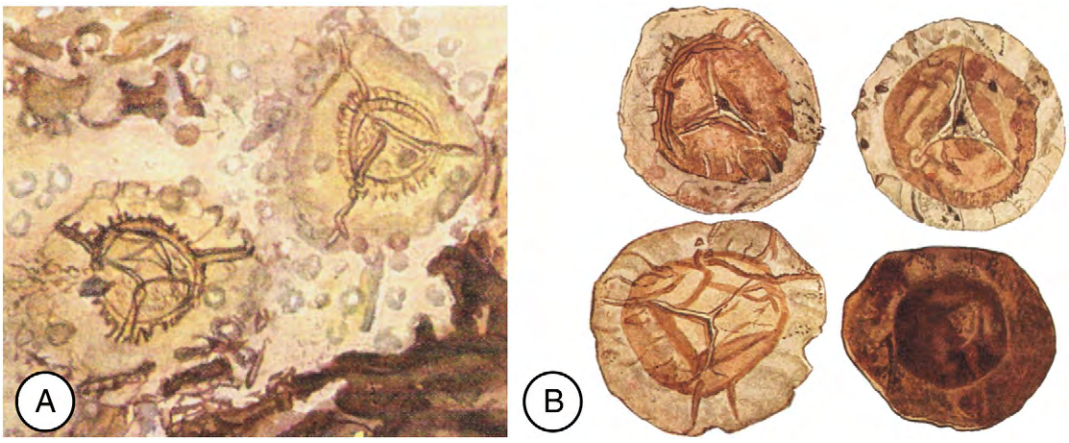


Fig. 5. Spores illustrated in colour by (A) Elovski (1930) and (B) Ergolskaia (1930). These are watercolour paintings, not photographs. The original light-grey background in Fig. 5B has been replaced by a white background.

from an electronic flashlight, produce cool, bluish-white colours. The human eye and brain usually compensate for these colour casts so well that we are rarely aware of them; however, photographic film and electronic image sensors do not, and the effects of different light temperatures on the overall quality of a photograph can be dramatic. Therefore, the camera setting has to be corrected for the colour temperature of the available light using the so-called white balance. Most digital cameras have predefined white-balance settings, e.g. for bright sunlight, shade, flash, and artificial light, as well as an automatic white balance (AWB) function that automatically corrects for the colour temperature of the given illumination. However, the AWB normally chooses an average value that is not necessarily correct (or wanted). All DSLR and most compact cameras therefore have a manual setting that enables calibrating the white balance by pointing the camera at a neutral grey or white card. A correct, manual setting of the white balance is necessary for photographing fossils, because these objects usually do not show a standard colour spectrum. Hence, the white balance should be adjusted each time the illumination is changed, including repositioning of the light sources. This process only takes a few seconds and should become automatic. Unfortunately, white balancing is often ignored; illustrations of specimens with bluish or greenish colour casts are too common. Image processing software can also adjust colour settings, but it is of course better to capture true colours instead of correcting false ones. Again, digital processing of images should be kept to a minimum.

3.3. The choice of the background

Always use a neutral background for hand specimens. We suggest a black background that does not show any structure of itself. Many journals, including the Review of Palaeobotany and Palynology, do not allow cutting out specimens around their periphery. Backgrounds showing some kind of structure always distract the attention from the specimen; a lighter background will always give cast shadows of the rock specimen. In our experience the best backgrounds are cloths of fine black velvet or synthethic fleece fabric, the latter being less shiny than velvet. The cloth can be draped over the sand bag that is used for increasing stability and levelling the specimen. Isolated dark objects such as carbonised seeds can better be photographed on a white background (see Section 3.6.4).

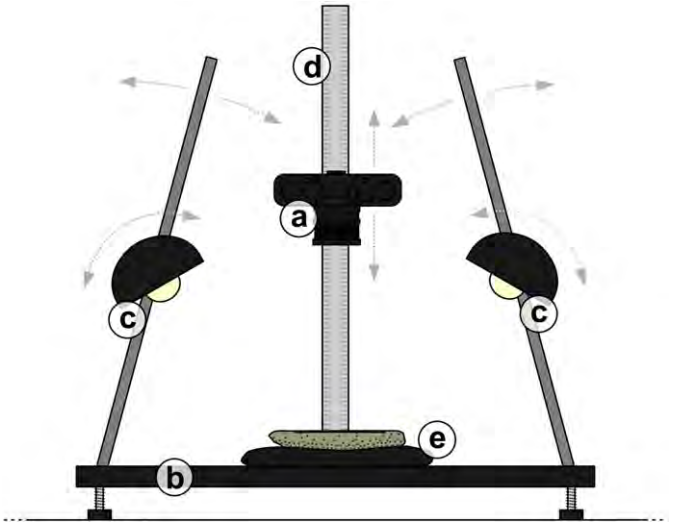


Fig. 6. Standard setup for photographing plant fossils, consisting of a horizontally adjustable camera with a macrolens (a) on a solid repro stand (b, d). The light sources (c) should be adjustable in every direction. The specimen is placed on a sand bag (e) to ensure stability and optimal positioning.

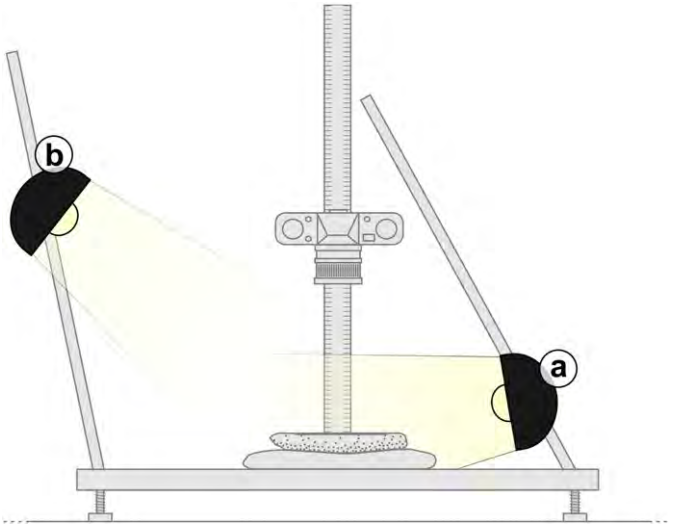


Fig. 7. Setting for oblique lighting, with a very low-positioned main light source giving (a) and a weaker second light source (b) to compensate for too strong cast shadows. For the effects of different lighting see Pl. I.

3.4. Light metering

At a given illumination, the exposure time and aperture size of the diaphragm control the amount of light that eventually reaches the image sensor. The more light the shorter the exposure time. A great advantage of modern cameras is that they feature an integrated light meter. Good cameras have several metering modes, i.e. (1) spot metering, in which only a very small area (1–5% of the viewfinder area) is measured, (2) centre-weighted average metering in which a larger area (up to 20%) is measured, and (3) field or average metering in which the entire field of view area is measured yielding an average value. The measuring mode depends on the object you want to photograph.

When field metering is used, the entire field of view is measured including white backgrounds and other very light parts of the image. If the field of view includes considerable proportions of white, the meter reading will be incorrect for the object that you want to photograph. The more white background or bright spots, the shorter the exposure time indicated by the meter reading will be. Then the fossil itself will be underexposed and appear too dark, and might not show relevant details. Similarly, if the object shows relatively high proportions of dark, the brighter parts may be overexposed. It is, therefore, better to make a series of exposures around the time shown by the meter reading, each with a slightly different exposure time, and choose the best. Most cameras have a correction mode that ranges from +3 or +2 to −2 or −3 with a series of incremental stops in between, lengthening or shortening the exposure time calculated by the light meter.

Finally, most digital cameras enable the user to adjust the signal gain of the electronic image sensor in order to control its light sensitivity (exposure index EI, commonly referred to as ISO setting or ISO equivalent). This forms the equivalent of choosing the film speed in conventional photography, i.e., the grain size of the photosensitive crystals in the film emulsion (expressed in ISO numbers). For our purpose, the ISO setting should be set to the least value possible, as a higher sensitivity not only shortens the exposure time, but also rather increases the image noise level/graininess. As a rule, the lower the sensitivity, the better the quality.

3.5. Depth of field

A great problem in macro- and microphotography is the limited depth of field (DOF). An optical lens is focussed on one plane that shows the optimal sharpness (focal plane); the portions in front of and behind this focal plane will gradually become blurred. The DOF is that area in front of and beyond the focal plane in which the photographed image appears acceptably sharp. At a given format size, the DOF is determined by (1) the focal length of the lens (i.e. the magnification), (2) the distance to the object, and (3) the aperture size of the diaphragm.

The DOF increases with decreasing focal length of the lens. The DOF also increases with increasing distance to the object: the closer the object, the shallower the DOF. If the distance to the object is shorter than the focal length of the lens, e.g., in case the objects to be photographed are very small, the DOF may be too limited to capture the object in acceptable sharpness. The simplest way to increase the depth of field is to close the aperture diaphragm. The aperture size of the diaphragm is expressed in *f*-stops, which is the focal length divided by the effective aperture diameter. The higher the *f*-number, the smaller the aperture size. Under given light conditions, closing the diaphragm will require a longer exposure time, but for us, this is unproblematic because our objects do not move. Lenses usually have their optimal performance when the diaphragm is about half open and the quality of the image decreases when the diaphragm is further closed due to diffraction effects. However, these differences are only minimal and can usually rather be measured than seen. Hence, for our purpose the diaphragm should be closed as much as possible in order to attain the maximum DOF.

The DOF beyond the focal plane is always greater than in front of the focal plane. Therefore, as a rule, rather focus on that part of the object that is nearest to you; the portions beyond the focal plane will become sharp when the aperture is closed during exposure. Particularly in macrophotography dealing with very small objects, this can be very critical. Therefore, manual focusing is highly recommended, because the infrared sensor does not know what should be sharp and what not. Many SLR cameras have a DOF control button that closes the diaphragm to the given aperture setting. The image in the viewfinder will eventually become pretty dark, but should still allow you to judge what is sharp and what not.

Special lenses with a very great depth of field have especially been developed for macrophotography. The most famous of these is the Zeiss Tessovar that was developed in the early 1960s and is still commonly used, with suitable adapters also in combination with DSLR camera bodies. The Canon MP E65mm F-2.8 1-5X Macro that requires manual focusing is a very attractive alternative. Such lenses are difficult to handle, but the results are rewarding.

3.6. Lighting

Photography is essentially creating an image by “writing” with light. Changing the position, the direction and the intensity of the light can have dramatic effects, in a positive as well as in a negative sense.

3.6.1. Direct and oblique lighting

In general, direct light from above gives images looking rather flat, without much three-dimensional relief (Pl. I, 1a, 2a; Pl. III, 1a). This can be ideal for showing the gross morphology of a flat object that contrasts well with its background, such as the outline of a carbonaceous leaf compression in a light-grey mudstone matrix. However, particularly when objects do not show much contrast but some relief, oblique lighting should be preferred, as the shadows resulting from the oblique position of the light source make even very fine structural detail visible (Pl. I, 1b, 2b). The main direction of relief-forming elements on the specimen (e.g. the venation pattern of a leaf impression) should never be oriented parallel to the direction of the light because then the effect will be minimal. Instead, the main orientation of the relief should be positioned more or less, but not completely, perpendicular to the light beam(s). Rotating the specimen with respect to the light source(s) easily helps to find the optimal position.

In palaeozoology, fossils are frequently whitened with a thin coating of ammonium chloride (NH_4Cl) or magnesium oxide (MgO) to obtain an evenly coloured fossil showing an enhanced relief under oblique lighting (Kier et al., 1965). When dealing with plant compressions, this method is generally to be avoided, because cuticles or other organic remains are easily damaged when the coating material is brushed off. However, coating may give very good results when applied to plant impressions or casts that lack organic material (see e.g. Rees, 1993; Wagner and Álvarez-Vázquez, 2010).

The lower the position of the light source, the longer the shadows. The effect is most obvious with a light source on one side only. This, however, may result in the image being overexposed at the side of the light source, eventually with strong cast shadows obscuring part of the fossil where the relief is strongest, and underexposed at the opposite side. Therefore, it is often better to have one main light source at one side and a weaker light source at the other side to compensate for negative effects (Fig. 7). It should be noted that structures apparent by differences in colour, e.g., delicate veins without relief, will not be accentuated. In fact, they tend to fade away with increasing obliquity of the light sources.

There is no golden rule how light sources should be positioned. The same is true for the orientation of the specimen. It is a matter of trial

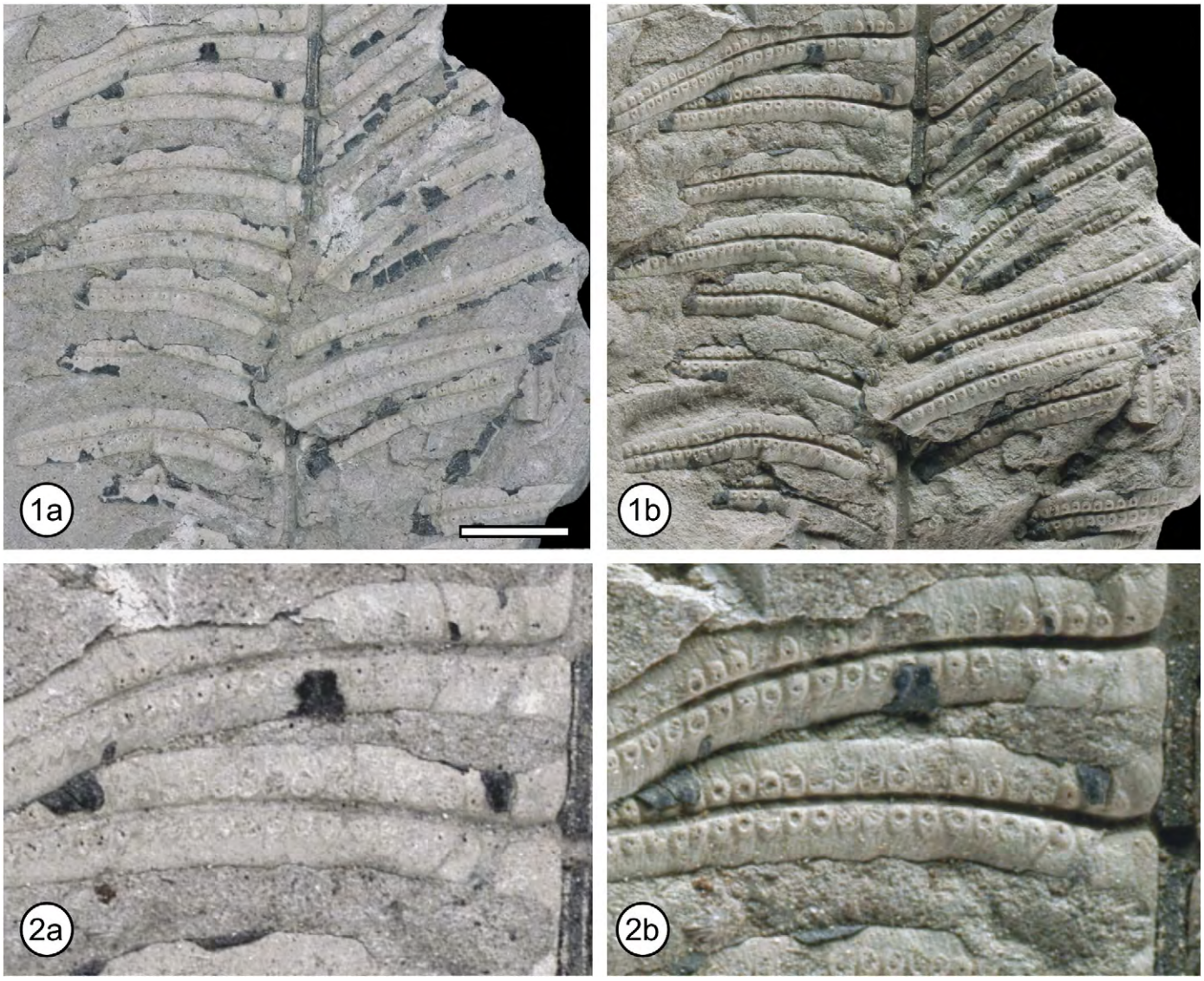


Plate I. *Phlebopteris muensteri* from the Pliensbachian (Lower Jurassic) of Bornholm, Denmark. All illustrated specimens are kept in the collection of the Forschungsstelle für Paläobotanik, Münster, except when indicated otherwise in the plate captions. Specimen PbO 2011/004.

1a. Specimen with two light sources at an angle of 45° Scale bar = 1 cm.
1b. The same specimen photographed in oblique light.
2a + 2b. Details of 1a and 1 b.

and error, and eventually experience. In order to get the perfect image it is often necessary to try many different options for the level and angle of lighting, and for the orientation of the specimen. The use of reflection boards, i.e., a simple piece of white paper, cardboard or any other material that reflects the light, may be very helpful to create a different lighting, e.g., to lighten up dark parts (Fig. 8).

Positioning and adjusting the light sources is the most important step in making a photograph. Adjusting the light to reach the optimal result may cost you some time. However, bear in mind that professional photographers often need a whole day for the perfect shot. When you think you have found the ideal lighting, make a series of images with different exposure times.

3.6.2. Diffuse lighting

Direct and oblique lighting often create very strong shadows. Strong shadows of specimens showing considerable three-dimensional relief may partly obscure the fossil. Particularly in dark specimens with a relatively strong three-dimensional relief, it is often difficult to discern where the margin of the actual specimen ends and the shadow starts. This can largely be avoided using diffuse lighting. Diffuse lighting is also the best method for fossils showing very little contrast but some three-dimensional relief. The easiest and cheapest way to make three-dimensional relief visible without getting strong shadows is to photograph specimens outside using normal daylight on a cloudy, overcast day without direct sunlight. The best results are obtained immediately after a rain shower when the light is very diffuse, giving very natural, saturated colours. Early photographers had no electric light sources but nevertheless got optimal results, and it still works perfectly!

Only slightly more expensive than natural daylight is the use of a light box (also called a light tent) in combination with artificial light. Light boxes are commonly used in commercial photography and for photographing objects showing little or no contrast but a clear relief, such as coins. A light box is an open box-shaped frame of which the

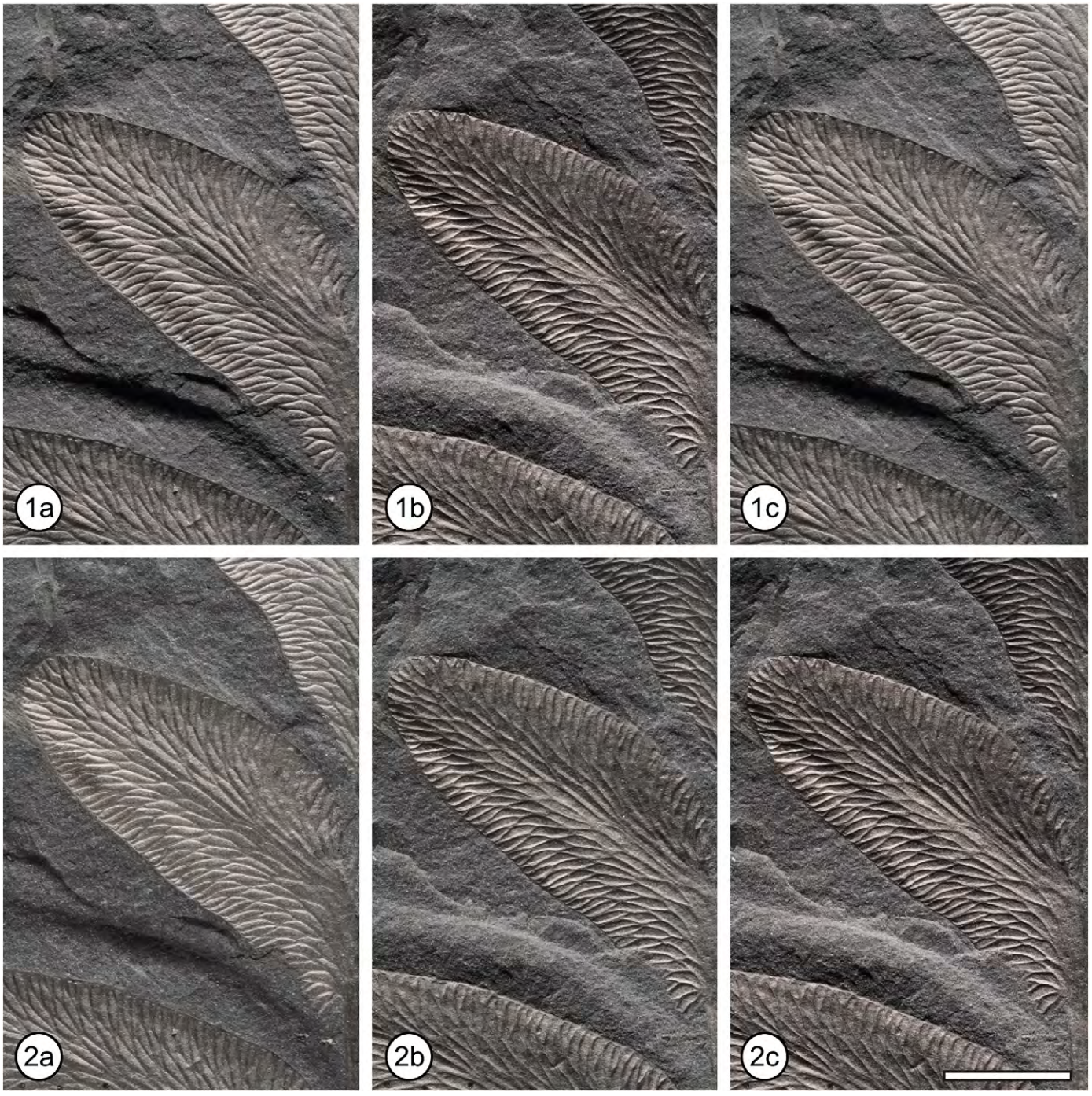
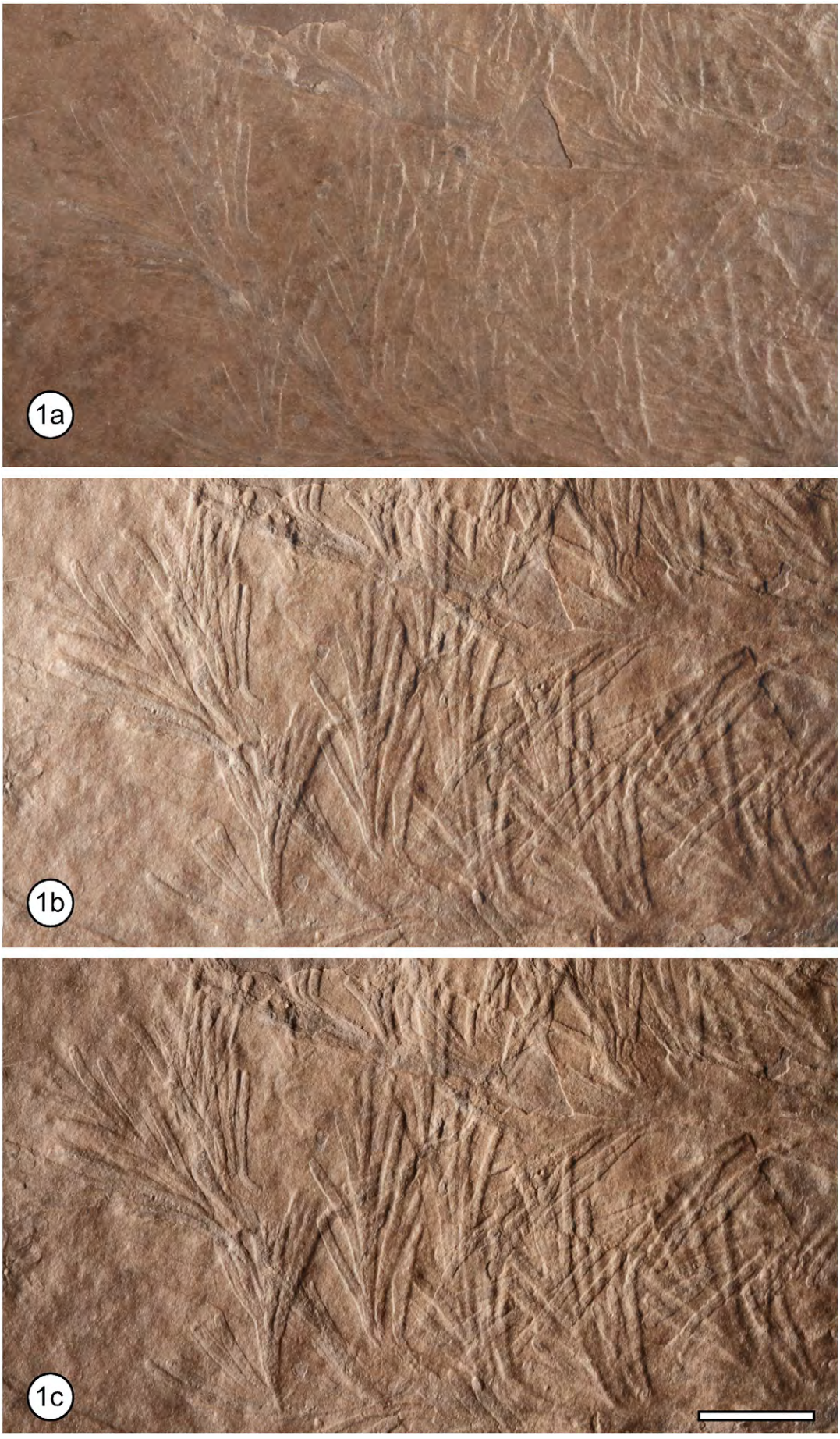


Plate II. A specimen of *Reticulopteris muensteri* from the upper Bolsovian (Pennsylvanian) of the Piesberg Quarry near Osnabrück, Germany, photographed using different settings of the light. Specimen PbO 2011/005.

1a–1c.	Photographs with direct oblique light (c. 30°).
1a.	Light from above and below.
1b.	Light from below. The upper part of the image is rather dark.
1c.	Light from above.
2a–2c.	The same setup as in 1a–1c but now the specimen is placed in a light tent. Strong cast shadows are avoided and the images look smoother.
2a.	Light from above and below, resulting in a rather "flat" image.
2b.	Light from below.
2c.	Light from above. Note that 2b and 2c are very similar. The lighting in image 2c is very even and all essential details are visible. Scale bar = 5 mm. All photographs without any post-exposure adjustments.

lateral sides facing the lamps are closed with a thin white cloth, white tissue paper or any other kind of white, sufficiently translucent material (Fig. 9; Pl. IV, 3). If desired, the backside can be closed with white cardboard. Light boxes are commercially available, but it is easy to build your own. The cheapest option is to use a stable, old cardboard box with windows cut in the lateral sides, and with an open



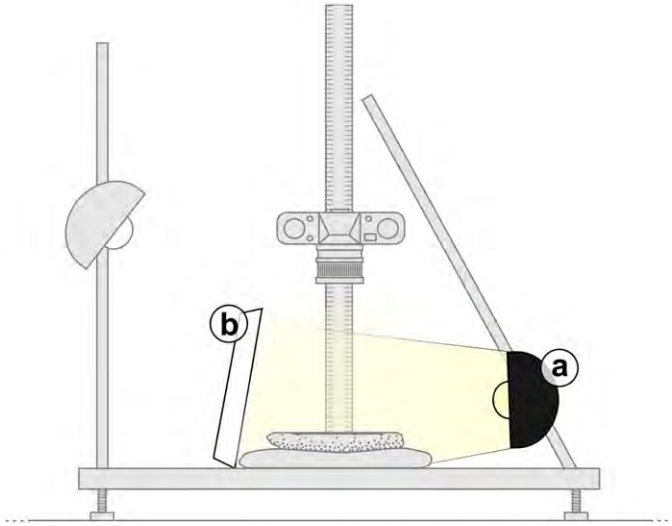


Fig. 8. The use of a single oblique light source (a) in combination with a reflection board (b) to avoid underexposure at one side.

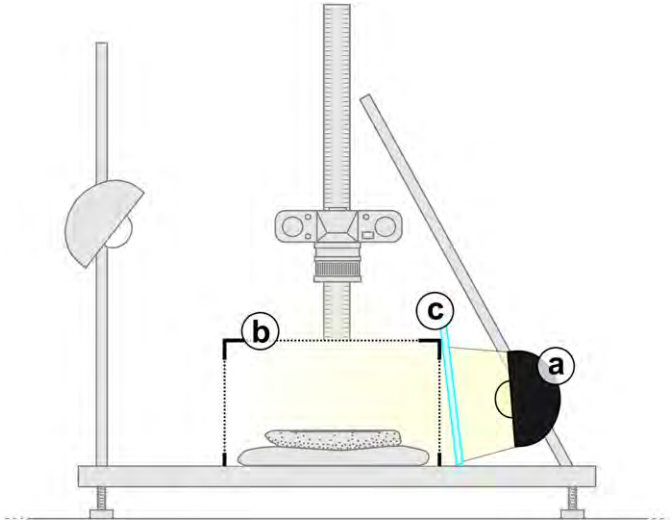


Fig. 9. The use of a light tent with a single light source (a). The light tent consists of a frame (b) with a plate of frosted glass (c).

front and top. We tried several materials as diffusion medium and the simplest solution was the best: glass plates that were used for grinding thin sections. These have a very finely frosted surface that diffuses the light in an optimal way, much better than milk glass. Ideally, images made using a light box will show a very clear three-dimensional relief without strong cast shadows or direct light reflections (Pl. II, notably Pl, II, 2c).

Diffuse lighting can also be created by using reflection boards. Karl-Hermann Haupt (1904–1983), a Bauhaus scholar who made many of the photographs reproduced in Gothan and Remy (1957) and Remy and Remy (1959, 1977), used a 'light box' consisting of three large pieces of white cardboard, and directed his normal light bulbs on the white cardboard instead of the specimen itself. This method produces a very diffuse lighting making all fine grey tones visible, without accentuating the granular structure of the rock matrix too strongly. Because of the little amount of available light, however, the exposure times can be very long. For instance, for a particular image in Kerp (1988; pl. XI, 1,2) a single 60 W reflector lamp was directed at a spot aside of the fossil, and a reflection board was used only to compensate the unidirectional illumination. The exposure time was 2 min using a cable release to keep the shutter open. Many DSLR cameras have a maximum exposure time of 30 s. In case the required exposure time exceeds this limit (and you do not have a cable release for manual control of the exposure), you may simply reduce the exposure time by further opening the aperture diaphragm. Each incremental increase of the diaphragm aperture (= one full *f*-stop) reduces the exposure time to 50%, e.g., 1 min at *f*/22 equals 30 s at *f*/16. Keep in mind, however, that further opening of the aperture diaphragm reduces the depth of field.

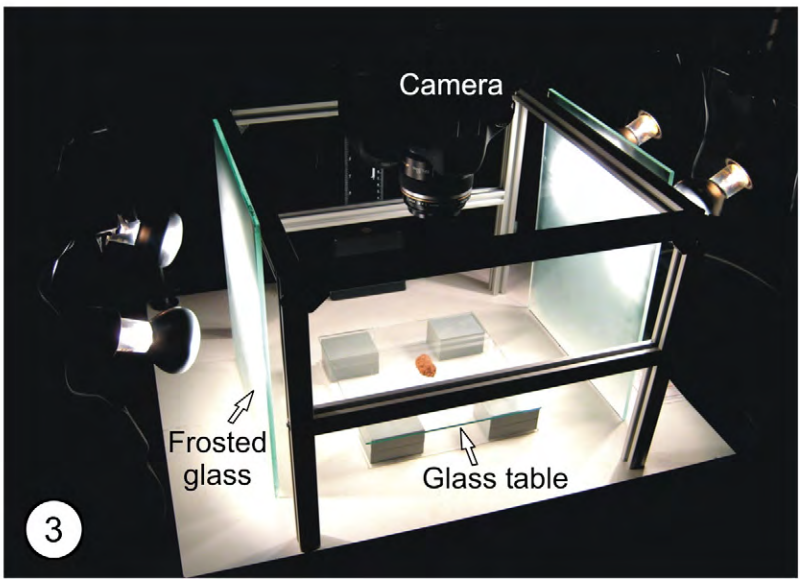
3.6.3. Oblique lighting from one side, dodging and burning

The major disadvantage of direct and diffuse oblique lighting from one side is that the side of the specimen facing the light source is usually overexposed, whereas the opposite side is underexposed (Pl. III, 1b). In classical wet photography this problem is solved in the dark room during printing the negative using a technique called 'dodging and burning'. The idea of this method is simple; overexposed parts on the negative film are exposed onto the print so much shorter that the final print appears evenly exposed. First, the appropriate exposure time for the brightest parts of the print (~darkest parts of the negative) is determined. Then, in order to selectively reduce exposure time of overexposed parts, a hand or a non-reflecting, non-transparent object, e.g., a piece of black cardboard, is moved between the lens of the enlarger and the overexposed parts of the photographic paper during exposure. The hand or the black cardboard has to be moved continuously in order to avoid sharp edges between the normal and the shorter exposed parts of the print. The opposite, i.e. exposing one part of the image longer than normal, is called burning.

This same principle can be applied also in digital photography in order to produce evenly exposed images of unevenly illuminated objects. In practise, this means that you move a dark, non-reflecting, non-transparent object—e.g., a piece of dark cardboard—between the camera lens and the object during exposure (Fig. 10). The longer the exposure time, the easier it is and the better it works. Therefore, use the smallest diaphragm which also gives the greatest depth of field; this automatically implies a long exposure time. If the exposure time is still too short to adequately control the effect, the light should be dimmed (mind the white balance!). Make a few images with different exposure times in order to determine the appropriate exposure time for the darkest part of the object; the lightest parts will then be overexposed. Then, during exposure, the piece of cardboard is moved about halfway between the front of the lens and the object in order to reduce the exposure time for that part of the image that would be otherwise be overexposed. A couple of trials are usually unavoidable. However, the result will be a very evenly exposed image requiring only minimal further processing (Pl. III, 1c).

Plate III. An impression specimen of *Dichophyllum flabellifera* with weak relief from the Lower Permian of Cabarz, Thuringia, Germany, photographed under different light settings. Specimen PbO 2011/006.

1a. Direct lighting with two lamps at each side at an angle of 45°.
1b. Oblique lighting from one side (left) used in combination with a light tent.
The image shows outlines of the pinnules very well but the left part of the image is overexposed (too light).
1c. The same setup and lighting as in 1b but dodging during the exposure results in an evenly exposed image. Scale bar = 1 cm. All photographs without any post-exposure adjustments.



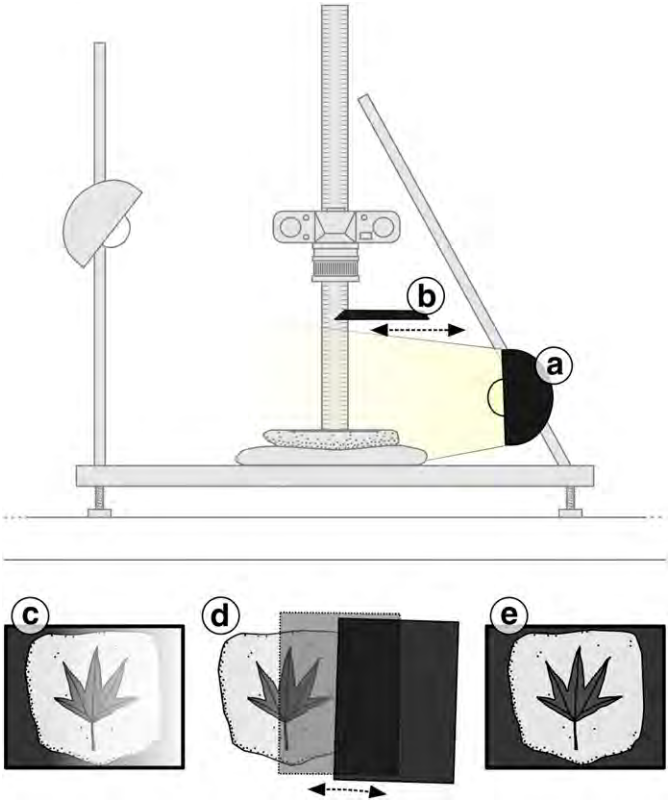


Fig. 10. The effect of dodging. The right side of the specimen will be overexposed (c) because oblique lighting from just a single light source at one side (a) is used. In order to reduce the exposure time for the right side of the image, a piece of black cardboard is moved between the lens and the object (b, d) during exposure. Dodging results in an evenly exposed image (e). For the effects of dodging see Pl. II.

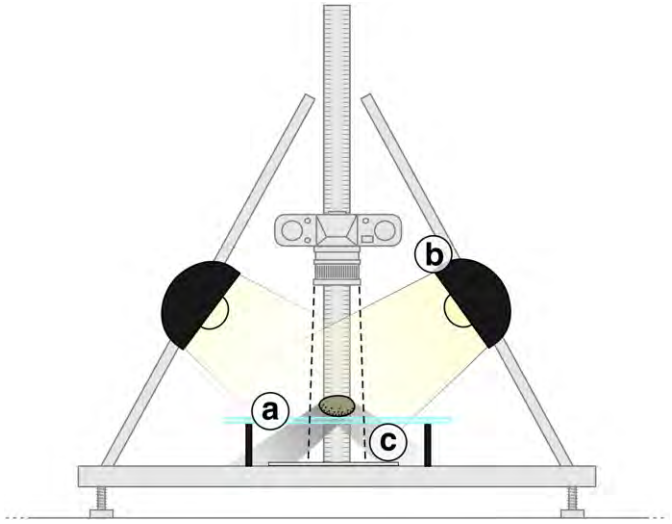


Fig. 11. Setup of a glass table for avoiding cast shadows when photographing dark objects with a strong relief on a light background. The specimen is placed on a table consisting of clear glass (a). When the light sources (b) are positioned at an angle of c. 45° the shadows will fall outside the field of view (c). For the effects of the use of a glass table see Pl. III.

3.6.4. Avoiding casts shadows of isolated, thick objects such as seeds

Using direct lighting for isolated objects with a considerable three-dimensional relief, such as seeds, results in very strong cast shadows (Pl. IV, 1a, 1b). Especially when seeds are very dark, like coalified seeds from brown coal deposits, it is often merely impossible to determine the outline of the seed. Strong cast shadows can be avoided by using a ring light. Ring lights, however, give images without much three-dimensional relief; the entire image appears very 'flat'.

Much cheaper and much more effective than a ring light is the so-called glass table, a clean, unscratched glass plate on which the objects are placed. The glass table is placed above a neutral, preferably white background and the objects are illuminated from left and right above at oblique angles (Fig. 11, Pl. IV, 3). If the distance between the glass table and the ground plate is large enough, the cast shadows will fall outside the field of view. If desired, the position of the lamps can be changed to accentuate the surface relief (Pl. IV, 1c, 1d, 2). For smaller three-dimensional objects, such as *Vitis* seeds, a simple plastic petri dish that is placed upside down can serve as a glass table.

For photographing dark seeds on a light background it is preferred to use spot metering or centre-weighted average metering, depending on the size of the object. Then it is of course necessary that the object is positioned in the centre of the field of view when the measurement is made, but several cameras have a function to save and store the meter reading so that the objects can be moved aside after metering.

3.7. Enhancing the contrast

A good image should be well-defined, but not have too strong contrast. Some plant fossils can be difficult to photograph because they show very little contrast to the surrounding sediment. In case the material of the actual fossil differs from that of the matrix (i.e., in compression specimens or some casts), the contrast can be increased considerably by using polarising filters, an immersion fluid, or a combination of both.

3.7.1. The use of polarising filters to enhance contrasts

The use of polarising filters in plant-fossil photography in order to increase contrasts was first introduced by Schaarschmidt (1973) and already applied by several palaeobotanists, e.g., Grauvogel-Stamm (1978) and Kerp (1983), several years before it was claimed to be a new application in palaeontology (Boyle, 1992; Rayner, 1992). The method is briefly outlined in Bengtson (2000). The effect is greatest

Plate IV. The use of a glass table prevents strong cast shadows. In combination with a light tent.

1a–1d.	A *Pararaucaria patagonica* cone from the Jurassic of Cerro Cuadrado, Argentina, photographed using different lightings. Specimen PbO 2011/007.
1a.	Specimen positioned on white cardboard with two lamps on each side causing strong cast shadows.
1b.	Specimen positioned on a milk-glass plate: the cast shadows are less strong.
1c.	Specimen positioned on a glass table: cast shadows are avoided despite the use of direct light from two sides.
1d.	Specimen positioned on a glass table in a light tent (see Pl. III, 3): no cast shadows, and the surface of the specimen looks much softer. Scale bar = 1 cm.
2.	A cone of *Pinus* sp. from the Miocene of the Lower Rhine Embayment, Germany. The specimen was placed on a glass table in a light tent for diffuse illumination making enough detail in the black fossil visible (see Pl. IV, 3). Note that the image shows a good three-dimensionality and a high amount of detail, and that strong cast shadows are avoided. Specimen PbO 2011/008. Scale bar = 1 cm.
3.	A glass table with a sheet of clear, clean glass in a light tent. The light tent consists of an aluminium frame with two frosted glass plates on the left and right side. This setup was used for making the photographs shown in 1d and 2.All photographs without any post-exposure adjustments; images have only been clipped to fit on the plate.

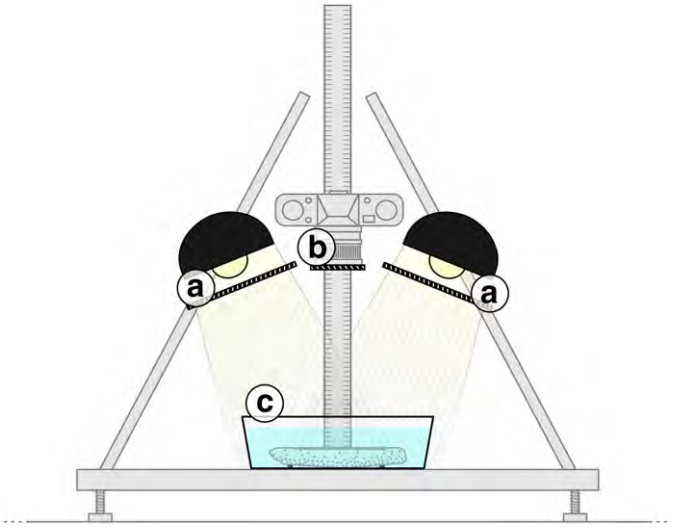


Fig. 12. Photographing specimens showing little contrast using immersion and polarised light. A polarising filter is placed in front of each light source (a); be sure that the direction of the polarisation is identical. The camera lens is equipped with an adjustable polarising filter (b). The specimen is placed in a basin with immersion fluid (c). For the effects of the use of polarised light in combination with immersion see Pl. IV, 1–3 and Pl. V.

when the light is reflected directly; the lamps should therefore be equipped with fixed, linear-polarising filters (= polarisers) and positioned closely at each side of the camera, on which a corresponding circular polarising filter (= analyser) is mounted (Fig. 12). The effect can be regulated by turning the analyser on the camera lens (Pl. V, 1a, 1b, 2a, 2b). As a matter of course, any other sources of (non-polarised) light should be switched off or reduced to a minimum. Even though the contrast can be enhanced considerably by using polarising filters, this method may have several unwanted side effects. The reproduction of the natural relief of the specimens will be strongly reduced even under oblique lighting; the image usually looks 'flat'. Also, coalified compression specimens may appear entirely black, in which case the fine details, such as venation patterns, may no longer be discernable. More problematic even is that true black colours may become bright to dark blue at maximum extinction, especially when specimens are coated with varnish. Light reflections, which will become enhanced due to the generally long exposure time, may show bluish glares as well. This is not a problem when images are printed in black-and-white, but it is very disturbing when they are printed in colour. Therefore, it should be preferred to adjust the circular analyser on the camera lens to just a little bit less than maximum extinction, so that fine details are still to be seen and undesired colour glares can be largely avoided. Because polarising filters affect the spectrum of light reaching the image sensor, image colours will often turn greenish or bluish. Therefore, as always, perform a manual white balance at the given lighting and polarisation setting before taking the image in order to avoid these false colours.

3.7.2. The use of fluid immersion to enhance contrasts

The contrast between the fossil and the rock matrix often increases considerably when specimens are submersed in (or wetted with) a clear fluid. This method also eliminates reflections from shiny surfaces and gives the fossil more intense colours (Pl. V, 1c). In addition, traces of manual preparation, such as groove and scratch marks, largely disappear. As a result, the sediment matrix will appear very smooth and even, providing a good and ideally well-contrasting background to the actual fossil. Another advantage is that the immersed fossil appears shallower than it in fact is. This means that the three-dimensional relief is largely lost, whereas the depth of field increases with 20–30% depending on the refraction index of the immersion fluid.

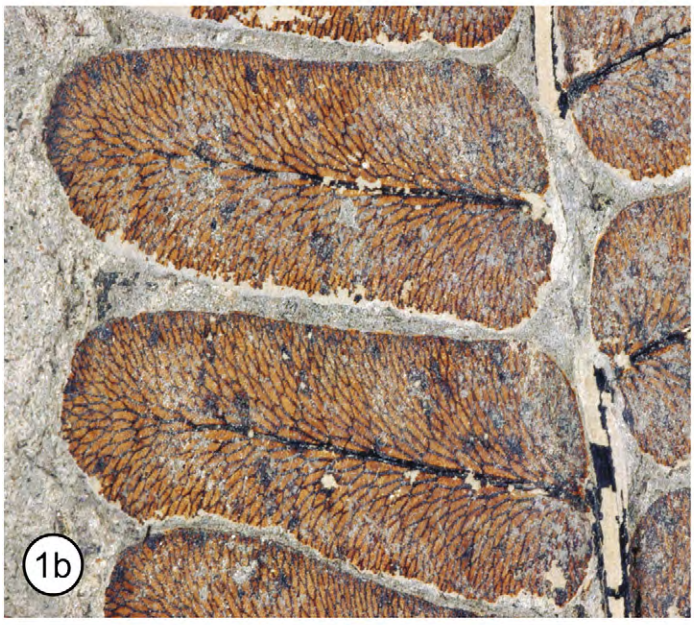
In a few cases, e.g., when dealing with very large specimens, simply wetting that portion of the specimen to be photographed may give good results, given that the specimen surface is sufficiently even and the fluid film deep and stable enough. In general, however, the object should be submersed completely in order to avoid light reflections from uneven portions of the fluid surface. The fossils are therefore placed in a container filled with the immersion fluid (Fig. 12, Pl. V, 3). In order to better control the illumination and to minimise unwanted light diffusion, the container should consist of a dark, non-reflecting material or of glass, in which case it should be placed on a dark piece of cloth. Special attention should be paid to avoid vibrations; the table and copy stand should be absolutely stable, as each tiny vibration will cause movements of the fluid surface, which in turn results in blurred images.

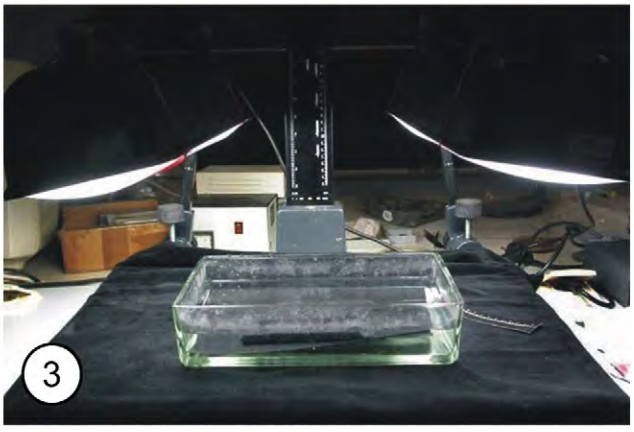
The immersion liquid should be transparent and should not react with the fossil or the rock matrix. Also, the immersion fluid should quickly penetrate pores and voids of the rock matrix. Otherwise, you will see a continuous stream of small air bubbles escaping from the specimen. Ethanol, xylene, and many other colourless organic solvents can be used as immersion fluids. Xylene and ethanol have an excellent refraction index close to that of quartz, and the surface tension is very low. Many of these organic fluids, however, are highly volatile (particularly when used under hot lamps) and to some degree harmful to health. Therefore, photographing fossils under such immersion fluids should either be done outdoors or in a large, well ventilated room; inhalation and skin contact should strictly be avoided. Although the optical properties of xylene are even slightly better than those of ethanol, we prefer to use ethanol because it is less harmful. Some people use glycerine as immersion fluid. Although the refraction index of glycerine is excellent, glycerine has several disadvantages. Pure glycerine is very thick and sticky, and may start to show "schlieren" when it contains a minimal amount of water. Glycerine is very prone to dust particles; they cannot be removed from its surface and cause unwanted artefacts in the images. Moreover, in contrast to other organic solvents, glycerine does not easily evaporate and it always leaves dark stains behind. The only way to remove glycerine is by rinsing with hot water.

In most cases, the use of plain water is unsuitable for clayey sediments because clay minerals will absorb water and begin to swell up, which will eventually result in the specimen beginning to disintegrate. Another problem is that the surface tension of water is very high; dust particles on the water surface tend to move constantly,

Plate V. The use of polarised light increases contrast but reduces the relief (1b, 2b). Polarised light can be used in combination with immersion fluids (Plate IV, 1c, 3, Plate V, 2).

1a–1c.	*Barthelopteris germarii* from the middle Stephanian of Montceau-les-Mines, France. Specimen L 2233.
1a.	In normal light.
1b.	In polarised light.
1c.	In polarised light in combination with ethanol immersion, Scale bar = 5 mm.
2a–2b.	*Archaeopteris roemeriana* from the Famennian of Goé, Belgium. Specimen PbO 2011/009.
2a.	In normal light.
2b.	In polarised light. Scale bar = 5 mm.
3.	The setup for photographing specimens under immersion with two light sources, each with a polarising filter and a camera with a polarising filter.





which produces fuzzy white lines in the photograph due to the long exposure time. Nevertheless, using clean water as immersion fluid can yield very good results when dealing with well-cemented siliceous specimens. The water surface can be cleaned from floating dust particles by gently adding a few drops of detergent right before the exposure; the formation of soap bubbles should of course be avoided. This user-friendly water immersion method worked very well for a collection of late Visean fossils from the Rhenish Slate Mountains (Germany). The dark-grey silicified limestones contain barely visible adpressions of very delicate plant remains. Under normal daylight the fossils are only visible when the slabs are viewed under an acute angle. When seeing the fossils is already very difficult, documenting them adequately is even more problematic. However, the combination of water immersion and polarised light made details visible that could not be seen otherwise, not even in oblique light (Pl. VI).

3.8. Photography in museums

Good images are essential for teaching. The best specimens are usually on display in museums, but the enthusiasm of museum staff for removing a specimen from a permanent exhibit for making a single image is often limited. In some museums photography is prohibited. In many museums photography is allowed, but the use of tripods is virtually always forbidden. In some museums also the use of a flash is forbidden. The often limited amount of available light, the special illumination that is often used to highlight (part of) the fossil, the display behind glass and reflections of the glass often make photographing in museums very difficult (Pl. VII, 1). Despite these problems, it is often possible to make good images that are suitable for teaching, even with small digital pocket cameras (as long as they have a macro mode).

If using a flash is allowed, it is advised to use it for larger free-standing or -hanging specimens that are not behind glass. The use of flash gives very evenly lighted, though somewhat hard images. The use of indirect flash with a reflection board or a diffuser, as are commonly used in portrait photography, will result in softer images. The photographer is often forced to choose a position aside from the fossil and to "shoot" at an oblique angle. The distortion caused by the perspective can easily be corrected with an image processing programme. Because objects are usually small to medium-sized, a simple flash is usually sufficient, even the built-in flash of a small digital pocket camera (Pl. VII, 4, 5).

Objects behind glass are more difficult. If possible, use the manual focusing option; the autofocus may focus on the glass of the show case. When flash is allowed, this is the best option. The problem, however, is that the flash is bounced back by the glass resulting in a reflection when the fossil is directly in front of the camera. In order to avoid these reflections, an oblique angle is much better. A part of the flash light will still be bounced back but it will not be recorded by the camera (Fig. 13). This may result in very good images (Pl. VII, 2, Pl. VIII). Another, even better option is to use the available light. Also in this case reflections are often a problem together with long exposure times. Particularly, small digital cameras with zoom and macro modes are very useful. Switch to the macro mode and gently lean the front of the camera lens to the glass, this will largely eliminate reflections (Pl. VII, 3). The working distance is normally enough to get sharp images when the macro mode is used. Use the zoom mode to select the size of the view. Long exposure times of 1/8 or 1/4 second are not exceptional. Normally, it is impossible to make sharp images without using a tripod. However, the camera gently leans on the glass and the glass window of the show case provides some stability, enabling such long exposure times. Reflections cannot always be completely eliminated; sometimes, a very faint colour contour of the photographer may be visible. Therefore, it is advised to wear dark, neutral clothing, preferably grey or black without strong differences in colour.

4. Macrophotography

Very small specimens and details as well as polished and thin sections are usually best photographed using a stereomicroscope equipped with a digital camera head. The optical path should be direct (= vertical, without any angles requiring prisms and mirrors), because this gives the best results. Depending on the object to be photographed, incident light, transmitted light, or a combination of both may be used.

4.1. The equipment

Conventional and digital SLR camera bodies can be mounted on a stereomicroscope or microscope using special adapter devices. More stable and much easier to handle, however, are special digital microscope cameras that are connected to an independent control unit. The same camera can normally be used for stereomicroscopes and transmitted-light microscopes, provided that they require the same adapter (usually standard C-mount or T-mount adapters). If the microscope camera has a separate control unit with a relatively small display, it may be worth to connect a separate monitor, i.e., a large,

Plate VI. The effect of using fluid immersion in combination with polarised light. Two images of an impression specimen of *Diplopteridium teilianum* from the upper Visean of Becke-Oese, Sauerland, Germany.

1. without immersion in normal artificial light with two 60 W light bulbs at each side at an angle of 45°.
2. under water immersion with a few drops of detergent. Two daylight tube lights with polarising filters positioned at angles of c. 80° degrees were used for illumination; maximum contrast setting was used. Post-exposure editing included a slight contrast enhancement and an adjustment of the saturation. Specimen PbO OE 20a. Scale bar = 1 cm.

Plate VII. (see on page 136)

1. Palaeobotanical exhibition at the Národní Muzeum, Prague. This image shows the main problems, a poor illumination, at least for photographing fossils, and specimens behind strongly reflecting glass.
2. A silicified specimen of *Pecopteris* sp. from the Lower Permian of Araguaína, Brazil. The specimen, which is on display behind glass in the Museum of the Bayerische Staatssammlung für Paläontologie und Geologie in Munich was photographed with a small digital 4 Megapixel pocket camera using flash at an angle of c. 70°. Coll. Nr. BSPG 2002 XV 1000. Scale bar = 1 cm.
3. A specimen of *Lepidodendron aculeatum* from the Radnice Member, Kladno Formation (Bolsovian, Pennsylvanian) of the Mayerau Mine in Kladno, Bohemia, Czech Republic. The specimen is on display behind glass in the showcase shown in 1. The specimen was photographed with a small digital 4 Megapixel pocket camera using available light with the lens pressed to the glass to avoid reflections and to gain some stability. Inv. No. 05680, Acces. No. 27503/42. Scale bar = 1 cm.
4. A *Glossopteris* sp. leaf from the upper Buckley Formation, Upper Permian of Skaar Ridge, Queen Alexandra Range, central Transantarctic Mountains. The specimen was photographed with a small digital 6 Megapixel pocket camera using a flashlight at an angle of c. 75°. Collection of the Department of Ecology and Evolutionary Biology, University of Kansas, Lawrence (KS), USA, Nr. Pm 11 464. Scale bar = 1 cm.
5. Surface of a stem of *Cycadeoidea marylandica* from the Potomac Group, Cretaceous of Laurel, Maryland on display in the U.S. National Museum/Smithsonian Institution in Washington DC. This image was taken with a small digital 6 Megapixel pocket camera using flash at an angle of c. 75°. Accession number 256142; USNM number 42379. Scale bar = 2 cm.

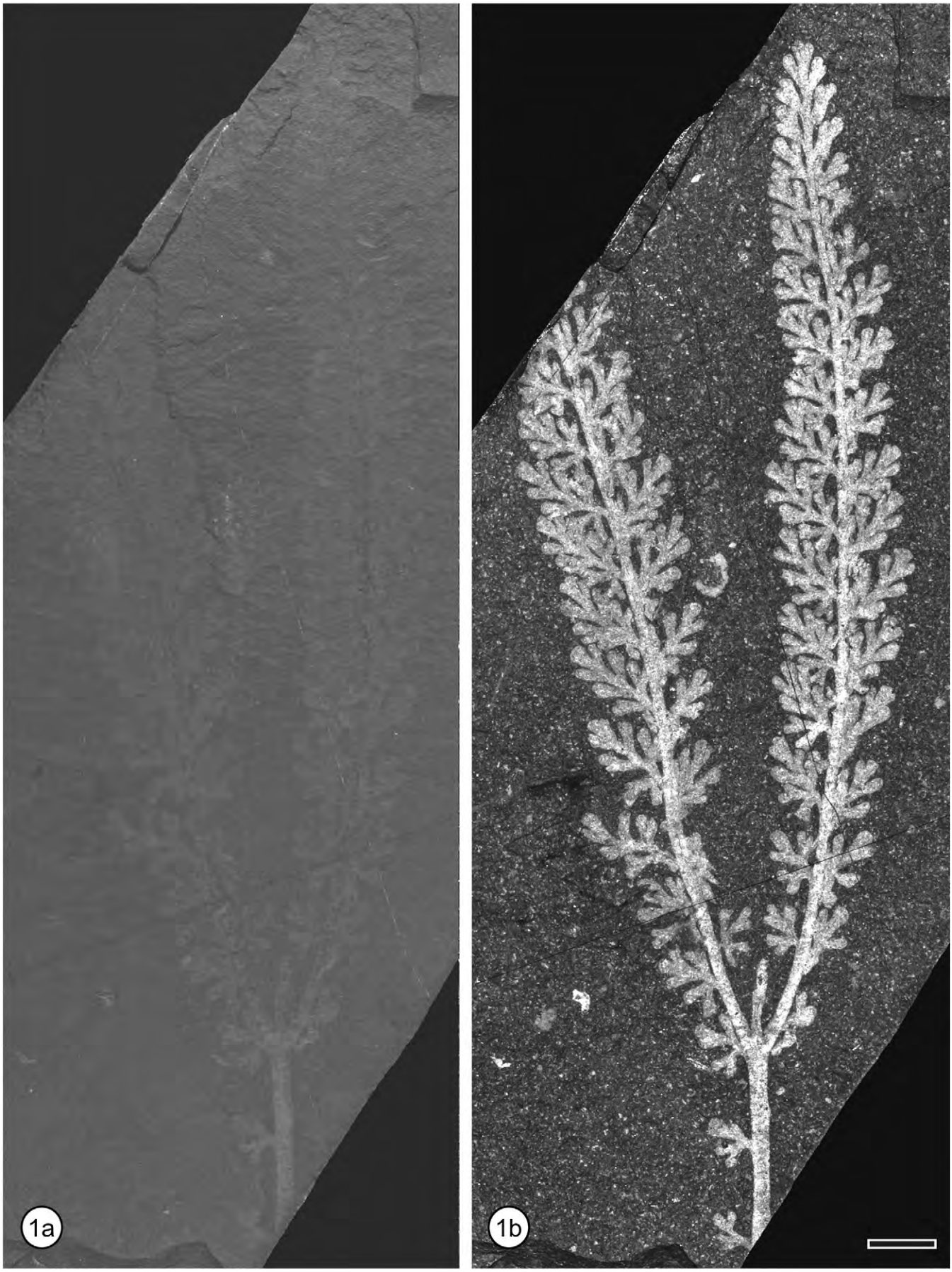


Plate VI.

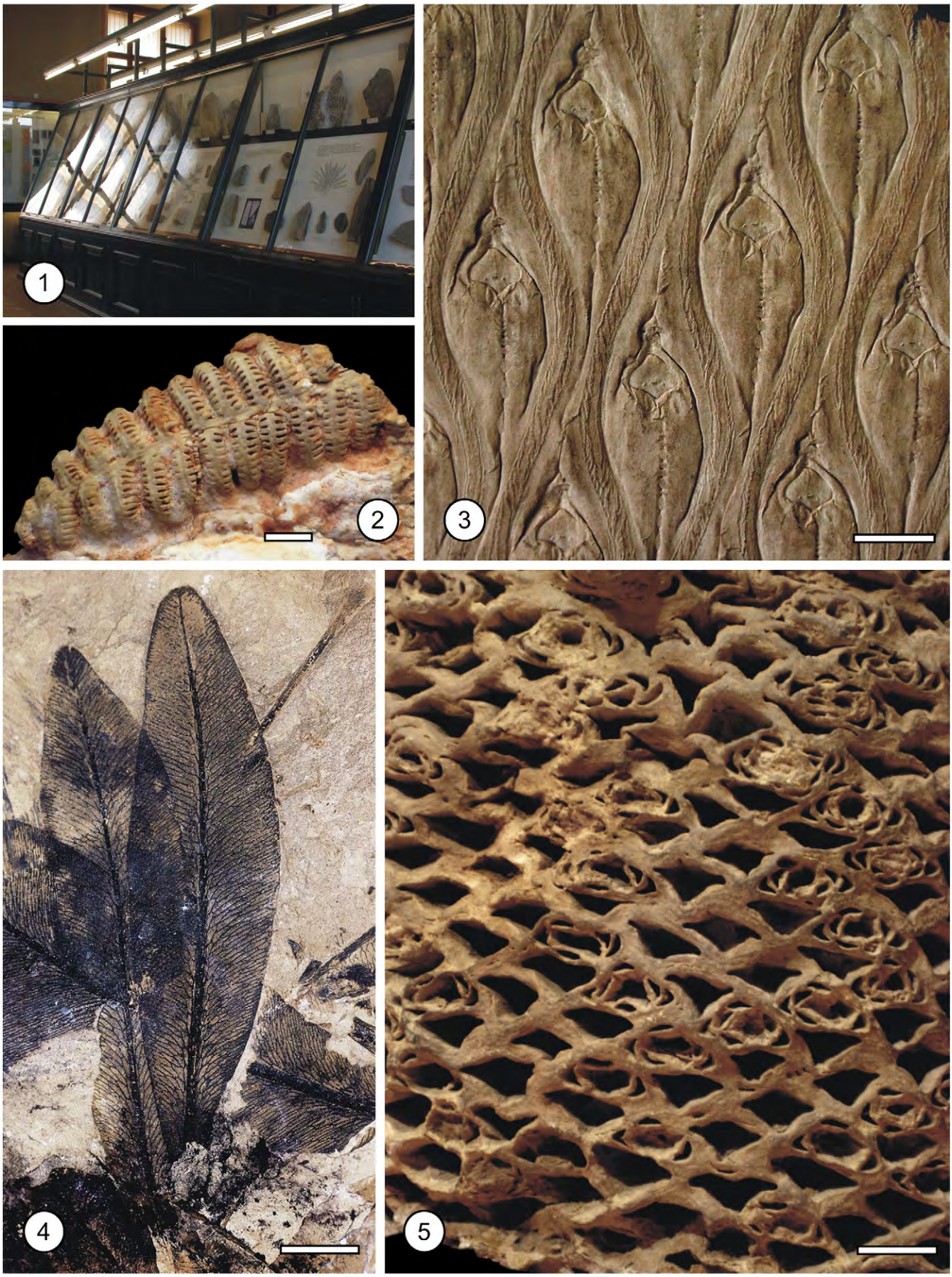


Plate VII *(caption on page 134).*

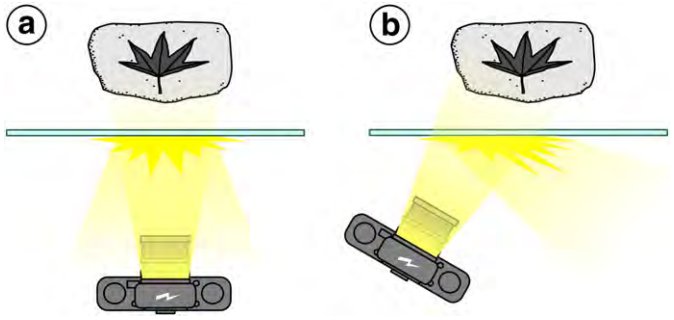


Fig. 13. Photographing specimens behind glass in a museum exhibit. A direct 90° flash (a) will result in reflections, whereas indirect flash at an angle of c. 70° will not cause any reflections. For examples of museum specimens photographed with indirect flash see Pl. VI, 2 and Pl. VII.

glossy computer screen; this gives a much better overview, and the larger view is very helpful for focusing. Be sure that the colours, brightness, and contrast settings of the additional screen are adjusted correctly and match both those of the camera display and those of a final print. Always focus using the screen and not the oculars of the (stereo)microscope, as the optical paths of oculars and camera sensor may differ. (Stereo)microscopes should be placed on a stable table in order to avoid vibrations.

4.2. The illumination

Stereomicroscopes can be equipped with a transmitted-light stageand with fibre-optic lighting or LED ring lights for incident illumination. We use a transmitted-light stage with LEDs that gives an evenly illuminated, naturally coloured background. LEDs have the advantage over halogen lamps that they produce negligible heat and cooling is not necessary, which means that LED light sources are also very quiet. Moreover, the LEDs last much longer (*c.* 30,000 h) and changing of light bulbs is no longer necessary. Transmitted-light stages should be switchable from normal to oblique transmitted light. For incident illumination, we definitely prefer a cold-light source with double-armed fibre-optics instead of ring lights. Even though modern LED ring lights have different lighting modes, with the ring being divided into four individually selectable segments, the possibilities for fine adjustment of oblique or indirect lighting are very limited. Moreover, at very high magnifications (>100×), the distance to the object may become so little that the central part, i.e. the object itself, may not be adequately illuminated. Fibre-optic lighting offers much more flexibility for adjusting the direction and angle of the lighting (Fig. 14). When necessary, small polarising filters or diffusion filters can be attached in front of the light guides. It is important that the light guides can be fixed in any desirable position; very useful are small holders with ball-head joints attached to the stage of the stereomicroscope.

It can be particularly difficult to photograph microscopic relief on adpression material, such as epidermal imprints, under oblique lighting using a stereomicroscope. The magnification may be so high that reflecting individual crystal surfaces in the rock matrix produce overexposed spots that result in a high noise level and too strong contrasts in the image. This can be largely avoided by using miniature reflection boards, which may simply consist of a folded strip of white paper placed aside the field of view. Direct the light beam away from the object and onto the reflection board, and adjust the illumination by playing with the angle and orientation of the reflection board (Fig. 14). Ideally, the resulting illumination should be very even, and the microrelief well accentuated with neither too strong reflections nor cast shadows.

Be sure that the room lights and any other lights than those used to illuminate the specimen are switched off in order to avoid unforeseen effects and reflections. We have once made a whole set of microscopic images that all showed a couple of faint but thick white lines, all in the same position. It took us some time to find out that it were reflections of the tube lights on the ceiling of the room. The problem could be solved by either switching off the room lights or by covering the oculars of the microscope with a black cloth during the exposure.

4.3. Very thin transparent objects such as cuticles

Overviews of very thin cuticles often hardly show any anticlinal walls. The use of oblique transmitted light accentuates the delicate cuticle relief, creating an effect that is somewhat reminiscent of the differential interference contrast used in transmitted light microscopy. When cuticles are extremely thin, the meter reading is often incorrect and it will be necessary to correct the exposure time.

4.4. Thin and thicker sections, coal ball peels

Thin sections and peels should ideally show an evenly illuminated background. Thin sections are normally photographed in transmitted light. However, this not always leads to good results because in some cases the resolution of fine details may be lost. In other cases, especially when slides are somewhat thicker, the image may look blurred with a very disturbing background in false colours. Neither incident light nor the combination of transmitted and incident light gives satisfying results. By using incident light and placing the slide on a plate of milk glass (i.e., a milky-white, translucent glass also known as opal glass), the disturbing background is eliminated and even the finest details can be seen in natural colours (Fig. 15). If necessary, a combination of incident and transmitted light can be used; this is just a matter of experimentation. We obtained the best results using a combination of oblique incident light (c. 90%) with a little bit of transmitted light (c. 10%) (Pl. IX–X). Field metering should be used for objects like coal-ball peels or thin sections, but corrections are often necessary because small light spots might influence the meter reading.

Coal-ball peels often show some irregularities in places where the coal ball shows cracks. Larger white surfaces also usually look somewhat irregular because of the differential dissolution of calcite and dolomite fills in the coal-ball cement. Other irregularities are due to air bubbles during peel preparation. In normal transmitted light and under incident light, these irregularities are very prominent, appearing as dark-grey or grey-bluish spots, as irregular mottled white surfaces, or because of coloured reflections. Placing the peel on a milk glass plate eliminates most of these undesired effects (Pl. XI). Coal-ball peels are covered with a glass plate to ensure that they lie completely flat, and to avoid curling up due to the heat of the lamps.

5. Microphotography

A good microscope is not necessarily a new one. All microphotographs in this contribution were made with microscopes that are 20 to 40 years old. If necessary, the illumination can be modernised by replacing the electric bulb by a halogen light. It is beyond the scope of this paper to discuss various types of light microscopy. The use of phase contrast (Zernicke, 1942a,b) and differential interference contrast according to Nomarski (Nomarski, 1955; Padawer, 1968; Allen et al., 1969) are well known and long since applied in palaeobotany and palynology (e.g., Grohne, 1957; Schaarschmidt, 1973) (Pl. XIII, 2–4). Nevertheless, in practise we often see images that can easily be improved. The most common problem results from incorrect illumination, which is commonly seen in dark objects showing a milky white glare in the centre of the image. The principle of optimal illumination was published more than a century ago

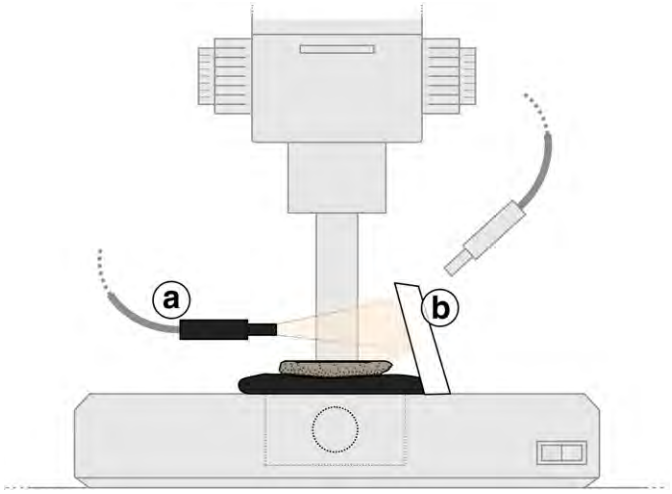


Fig. 14. The use of indirect light (a) using a reflection board (b) with a stereomicroscope.

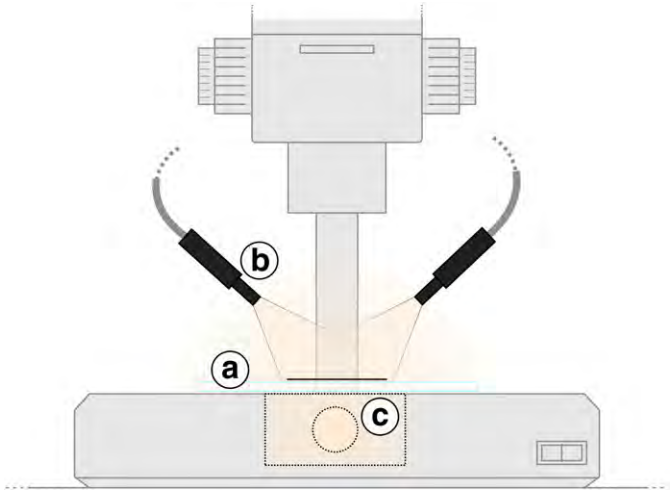


Fig. 15. The use of a milk-glass plate (a) below the specimen (thin section of coal-ball peel) using incident light (b) and some (~10%) transmitted light (c) to lighten up the background and eliminate the effect of surface structures. For the effects of the use of a milk-glass plate see Pl. VII, 5–6, Pl. VIII and Pl. IX.

(Köhler, 1893). The Köhler illumination not only prevents undesired glares of dark objects, it also gives an evenly illuminated background without accentuating dust particles that may be in the light beam, and it guarantees optimal sharpness (Pl. XIII, 1a, 1b). A few simple actions ensure optimal results: (1) First select the object and focus (Fig. 16a,b). (2) Then close the field diaphragm (placed above the lamp) and the iris diaphragm of the condenser. Now only a very small part of the view will be illuminated (Fig. 16c). (3) Adjust the height of the edges of the diaphragm ring are sharp (Fig. 16d). (4) When the light diaphragm ring is not positioned in the centre of the field of view, it should be centred (Fig. 16e). (5) When the iris diaphragm ring in the centre of the field of view is sharp (Fig. 16e), the field diaphragm should be opened until the entire image is illuminated (Fig. 16f). This can be checked on the display of the microscope camera. Realise that the captured image is only about one third of the entire field of view of the microscope. (6) Open the iris diaphragm of the condenser as far as necessary to get the desired depth of field. The correct Köhler illumination encompasses just a few simple steps. It is required for every exposure and it should become automatic for every microscopist. Be sure that the microscope lenses are clean. Especially oil objectives must be cleaned regularly; dust particles on the lens may also cause unwanted glares.

After the Köhler illumination has been set up, the white balance has to be adjusted. Move the object aside with the mechanical microscope stage until the field of view only shows the white background. Then set the white balance and move the specimen back to the desired position. Spot metering and centre-weighted average metering are normally preferred for microphotography, because the object rarely fills the entire field of view, except when you deal with cuticles or details at very high magnification.

5.1. Composite micrographs

Digital photography and post-processing offers the opportunity to increase image resolution and depth of field by assembling individual microphotographs into one composite image. Composite images can be produced by image stacking (vertical composites), image stitching (horizontal composites), and a combination of both (3D-composites).

5.2. Image stacking (or focus stacking)

In image stacking, a series of images taken at successive focusing levels is made. Then, only those portions of the individual images in which the parts of the object are in focus are merged together into a single image file (Pl. XII). The method is described in detail by Bercovici et al. (2009), who give very fine examples of composite images of spores and pollen grains. Several commercial and freeware software packages are available for this purpose (see Bercovici et al., 2009).

It needs to be pointed out, however, that an automated programme usually cannot determine accurately what part of which image belongs to the actual object. As a result, composite images made using automatic image stacking software may in some cases create disturbing artefacts and highlight unwanted features (e.g., dust particles, speckles, or cracks in the mineral matrix), which should better be left indiscernible and merged with the background. In this case, it may be preferable to assemble composite images 'manually': first, a stack of image layers, each containing one image of the series, is compiled using a graphics software programme. It is crucial to assemble this pile of image layers in correct order. Then, beginning from the top, the blurred areas (beyond the focal plane!) of each subsequent image layer are simply deleted using an eraser tool. It may be helpful to adjust the diameter and hardness of the eraser brush in order to obtain smooth transitions between individual layers. The so obtained stack of focussed image parts is then flattened into a single layer. Ideally, 'manually' prepared composite images should show no artefacts, and indiscernible transitions between individual focus layers.

Plate VIII.

1. A large specimen of *Laveineopteris piesbergensis* from the upper Bolsovian (Moscovian, Pennsylvanian) of the Piesberg Quarry near Osnabrück; Germany. This specimen is on display behind glass in the Ruhr Museum/Zeche Zollverein in Essen, Germany. Collection Stiftung Ruhr Museum Essen (ehem. Ruhrlandmuseum). The image was made with a small digital 6 Megapixel pocket camera using flashlight at an angle of c. 75°. The contrast and saturation have been adjusted; dodging was necessary for the upper part of the image. Specimen Nr. RE 551.735.220 A 1010 (ex Samml. Janzen, Seevetal). Scale bar = 10 cm.

5.3. Image stitching

The principle of stitching is combining a number of individual photographs into a single large composite image that shows details that would not be visible if the entire object had been photographed at lower magnification. This is not new because composite images have been made for a long time; paper prints were glued together to form a single large, high-resolution image.

Cuticles of complete pinnules show the distribution of stomata and other important features such as papillae and trichomes (e.g., Krings and Kerp, 1999; Krings et al., 2003; Pott et al., 2007); also the venation pattern is often clearly expressed in the cuticle (e.g., Krings and Kerp, 1998; Kerp and Krings, 2003). A single image of an entire pinnule at a relatively low magnification normally does not show the desired amount of detail due to the low resolution of the microscope and the camera (Pl. XIV, 1a, 2a).

5.3.1. Composite transmitted-light micrographs

Specimens are photographed with 4×, 5× or 10× lenses, depending on the cell size and the amount of detail that is needed. Before starting, the light bulb of the microscope should be centred very carefully. If the light bulb is not correctly centred, images are not evenly exposed, and one side will be darker than the other. This is not directly apparent when looking through the microscope or on individual images, but the effect is very disturbing when individual images are mounted in a composite image. Ideally, the seams (outlines of the original images) should not be discernible in composite photographs (Pl. XIV, 1b, 2b). For the same reason, we refrain from using differential interference contrast because in such images one side is often slightly darker than the other side.

Some microscopes appear to show optical aberrations, either chromatic aberrations or distortions, near the image margins. Therefore, it is advisable that the individual images overlap one another to a certain extent (20–25%), so that the margins can be cut off and only the undistorted part of the images is used. Many cameras have an automatic exposure mode and field metering. Because the different patches of cuticle may differ in colour, the use of the automatic exposure mode normally gives different exposure times, with the result that the individual photographs differ in brightness and colour. This is particularly apparent when the cuticle fills only a part of the field of view, e.g., at the pinnule margins. Therefore, it is crucial to use the manual exposure mode of the camera, so that all images are taken with the same exposure time setting and adjacent images will blend perfectly when mounted. Depending on the size of the pinnule, it will be necessary to photograph a number of parallel transects until the entire pinnule has been covered. The object should be oriented that way that it is easy to photograph transects using the mechanic stage for moving the specimen. In practise, the midvein or one of the long sides of the pinnule should by oriented parallel to the X or Y direction of the mechanical stage. When saving, each image file should be labelled very carefully, using a code indicating the position in the pinnule, e.g., by row and by line. Otherwise, mounting images becomes puzzling with many nearly identical pieces. It is also advisable to save the individual images in compressed file formats (e.g., JPEG) instead of the usually preferred un-compressed formats (e.g., TIFF), as many computers will find it difficult to process a composite image that consists of dozens of image files with a size of >30 MB each.

Several widely used commercial graphic software packages have an option for mounting images, e.g., for panorama photographs. We prefer to mount the composite images manually, however, because automated tools generally recalculate best matches between individual images, which often results in artefacts and blurry margins. The composite images shown here on Pl. XIV, 1b, and Pl. XV were mounted manually. A new file with a sufficiently large background layer is created. Then, on by one, the image files are imported as individual layers and assembled together. It is helpful to set each newly imported image layer to be semi-transparent; this way it becomes very easy to determine the correct position and optimal fitting of the overlapping parts of adjacent image parts. The overlapping image margins are then partially erased, so that only the undistorted, central parts of each image are eventually mounted together. Although this method is much more time-consuming than using an automated stitching programme, the quality of the final composite image makes manual

Plate IX. The effects of different illumination modes for photographing thin sections shown for a cross section through a rhizomatic axis of *Nothia aphylla* from the Lower Devonian Rhynie Chert, Scotland. It should be noted that the white balance was adjusted for each photograph. Nevertheless, in 1a, 2a, 3a and 4a the images are too bluish. 1b, 2b, 3b, 4b demonstrate post-exposure "adjustment" (colour adjustment and saturation), but the colours of these images are still unnatural. Only the use of a milk-glass plate under the slide (5a + b, 6) gives natural colours. Slide P. 2923.

1a + 1b. Transmitted light at an angle of 45°. —Surface structures (holes, cracks etc.) are accentuated, cells are reasonably well visible, at least in the lower and middle part of the axis.

2a + 2b. Transmitted light perpendicular to the surface of the slide. —Irregularities in the silica matrix are accentuated, particularly the large brownish vague spot covering most of the centre of the image. Where visible cell walls are a little bit blurred. Some parts (and cells) show up very light (= translucent), notably left and right of the conducting strand and at the margin left below, whereas others are very dark.

3a + 3b. Incident light, two spots each at an angle of 45°. —Cell walls are wel visible but many are strongly reflecting (light spots). Parts of the matrix are very dark, above the specimen, notably the upper right corner and left below. The white spot at the margin of the axis is now dark.

4a + 4b. Combination of transmitted (90°) and incident light (45°), both light sources at maximum power. —These images still shows some of the disadvantages of transmitted light, although the images are better than those of 2. Nevertheless, the cell pattern is not clearly visible.

5a + 5b. Slide positioned on a milk-glass plate using a combination of transmitted (90°) and incident light (45°), both light sources at maximum power. —A pretty evenly illuminated image, although some cells are reflecting too strongly.

6. Slide positioned on a milk-glass plate using a combination of incident light (45° at full power) and reduced incident light (c. 10%). —A very evely illuminated image clearly showing cell walls without unwanted light and dark spots.

7. Stereomicroscope with milk-glass plate; the slide is positioned on the milk glass plate.

Plate X. (see on page 142)

1. The final result using the image of Plate VIII, 6 after adjustment of contrast and saturation. The local slight glare, especially in the rhizoidal region is due to the thickness of the slide (>200 μm); the "glary" rhizoids are lying below the focal plane at the surface of the slide. Also "double" cell walls are a result of the thickness of the slide. Slide P. 2923. Scale bar = 500 μm.

Plate XI. Photographs of coal-ball peels from Seam Hauptflöz (Pennsylvanian, Bashkirian/Namurian C) of Zeche Carl Funke, Essen, Germany. Peels were photographed using two incident light sources positioned at angles of 45° combined with weak transmitted light to lighten up the light parts. Peels were positioned on a milk-glass plate to reduce undesired effects that can be caused by the surface relief of the peels. (see on page 143)

1. *Etapteris scottii*. Specimen PbO 2011/002. Scale bar = 1 mm.
2. *Calamostachys binneyana*. Specimen PbO 2011/001. Scale bar = 500 μm.

mounting worthwhile (e.g., Abu Hamad et al., 2008; Bomfleur and Kerp, 2010). In a carefully prepared composite image, the individual image parts match perfectly and no seams or fuzzy margins are visible, even at high magnification.

5.3.2. Composite epifluorescence micrographs

Cuticle preparation is a destructive method in which at least parts of a compression specimen are removed and eventually destroyed during cuticle extraction and maceration. This technique may therefore not be applicable when studying original type material. In other cases, cuticles may be very brittle and cannot be isolated from the specimen without falling apart because they are held together only by the underlying carbonaceous compression or rock matrix. If the material was not too strongly affected by thermal alteration, cuticles show an autofluorescence after irradiation with UV light (Van Gijzel, 1967, 1977; Friedrich and Schaarschmidt, 1977, 1979; Van Gijzel, 1979; Schaarschmidt, 1982), and can therefore be analysed using epifluorescence microscopy. Fluorescence intensity is generally weak at low magnification, and increases with higher magnifications. The major disadvantages of using higher magnifications are the limited field of view and also limited depth of field. Therefore, the preparation of horizontal and 3D composite micrographs is particularly effective in epifluorescence microscopy of plant cuticles. The first attempt to document larger overviews of fossil plant cuticles by

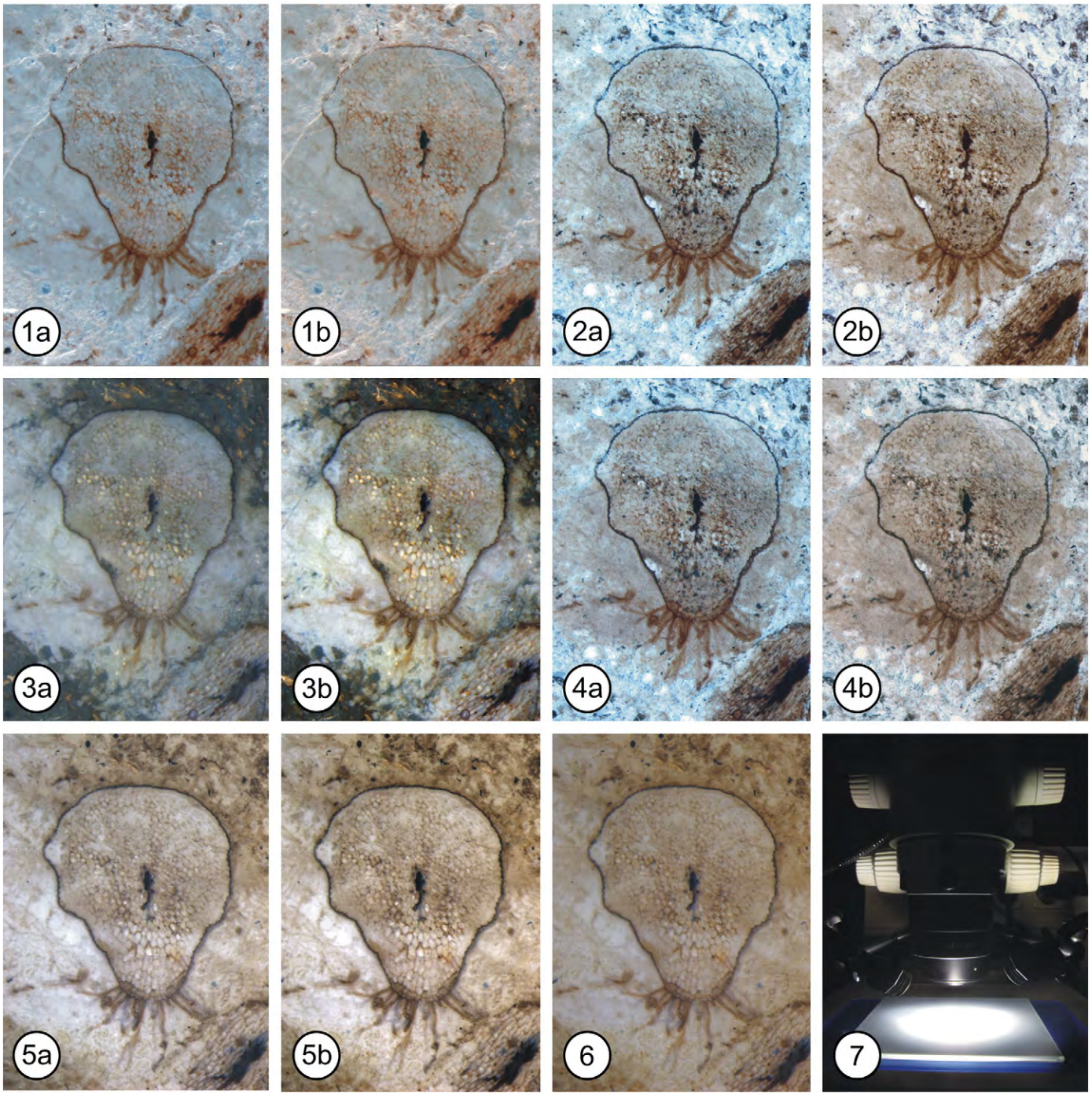


Plate IX.

Plate X *(caption on page 140).*

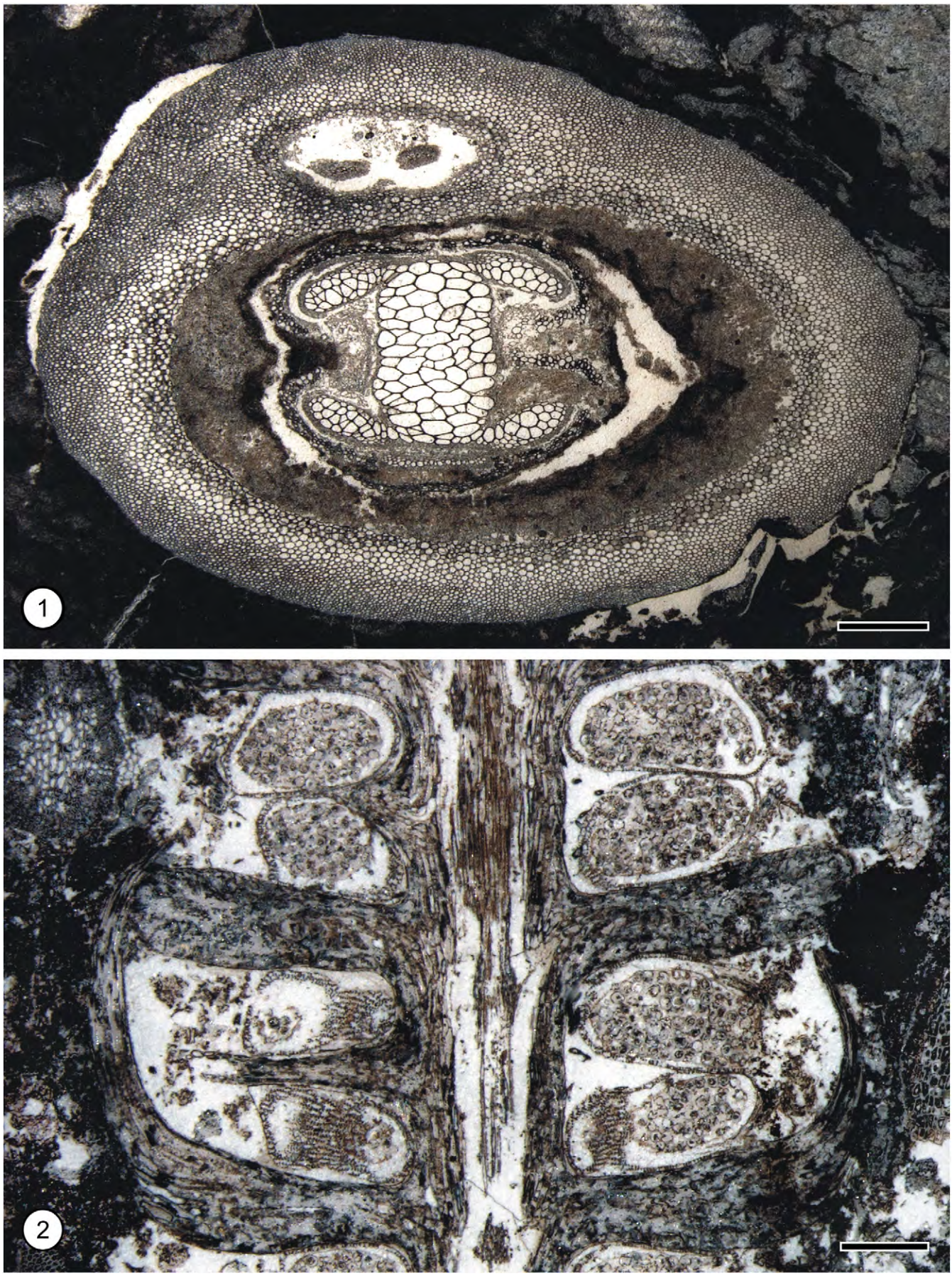


Plate XI *(caption on page 140).*

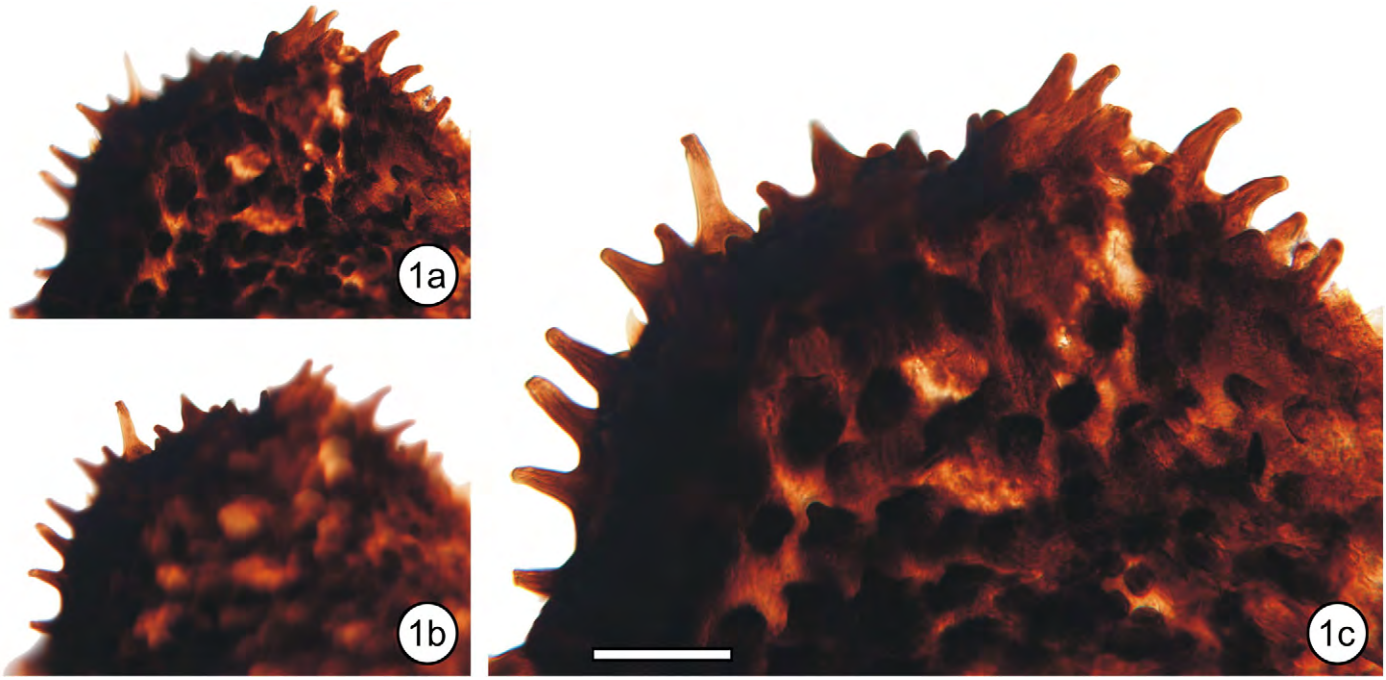


Plate XII. Apex of a strongly papillate conifer leaf of uncertain affinities from the Lower Jurassic of Section Peak, north Victoria Land, Transantarctic Mountains. Because of the very strong relief and three-dimensionality of this object, the depth of field is very limited. Images 1a and 1b were taken with the maximum field of depth at different focusing levels. Image 1c shows a combined image consisting of eight stacked photographs. Slide GIX SPP BB30b. Scale bar = 50 μm.

composite fluorescence micrographs was by Kerp et al. (1989, 1990) who published two composite images of a conifer twig, each consisting of around 40 individual images taken at 100x magnification. We later used digital composite epifluorescence imaging for preparing a composite image of a complete *Autunia conferta* pinnule (Bomfleur et al., 2007; Pl. XVI, XVIII). The method has since been very successfully applied and further modified for the study of fossil arthropod cuticles; Haug et al. (2008, 2009a,b) provided detailed descriptions and some very impressive examples of 3D composite fluorescence images.

The basic equipment consists of a standard fluorescence microscope with incident UV-illumination and a digital camera. The mechanical stage of the microscope, fine-adjustable in X and Y directions, should be robust enough in order to be able to work with larger, i.e., thicker and heavier, specimens. In order to be able to examine also thicker specimens, there must be sufficient space between the lens and the stage. Small specimens are mounted on a microscope slide. Larger specimens are placed on a plastic plate with one or two standard microscope slides glued to the lower side, so that it fits in the slide holder of the microscope stage and the specimen can be moved with the X and Y fine-adjustment knobs. Specimens should be mounted horizontally, so that the object surface lies parallel to the focal plane, which can usually be done by mounting them on a small clump of modelling clay. Specimens must be completely dust-free, because dust particles show very strong fluorescence intensity far greater than that of fossil cuticle. Depending on the nature of the specimen, dust particles can be removed with compressed air, by gently blowing or with a very fine brush.

In our case, the microscope is equipped with 5×, 10× and 25× lenses suitable for fluorescence microscopy. Microscopes are usually equipped with lenses that are corrected for the refraction caused by the presence of a cover slip. For direct observation of specimens with the fluorescence microscope lenses without cover-slip correction are preferred, but for lenses with a magnification of up to 25× it does not really play a role whether they are corrected for cover slips or not. For oil shales, Schaarschmidt (1982) prefers the use of a 25× water immersion lens, because it shows a stronger fluorescence. The specimen is submersed in a dish or low beaker filled with water that is placed on the microscope stage. However, water immersion cannot be used for specimens with a clayey rock matrix, because these easily fall apart. The microscope is equipped with standard incident UV illumination. We used a HBO 50 mercury lamp in combination with a filter block consisting of an excitation filter (UV + blue: 350–460 nm), a dichromatic mirror (beam splitter, RKP510) and a barrier

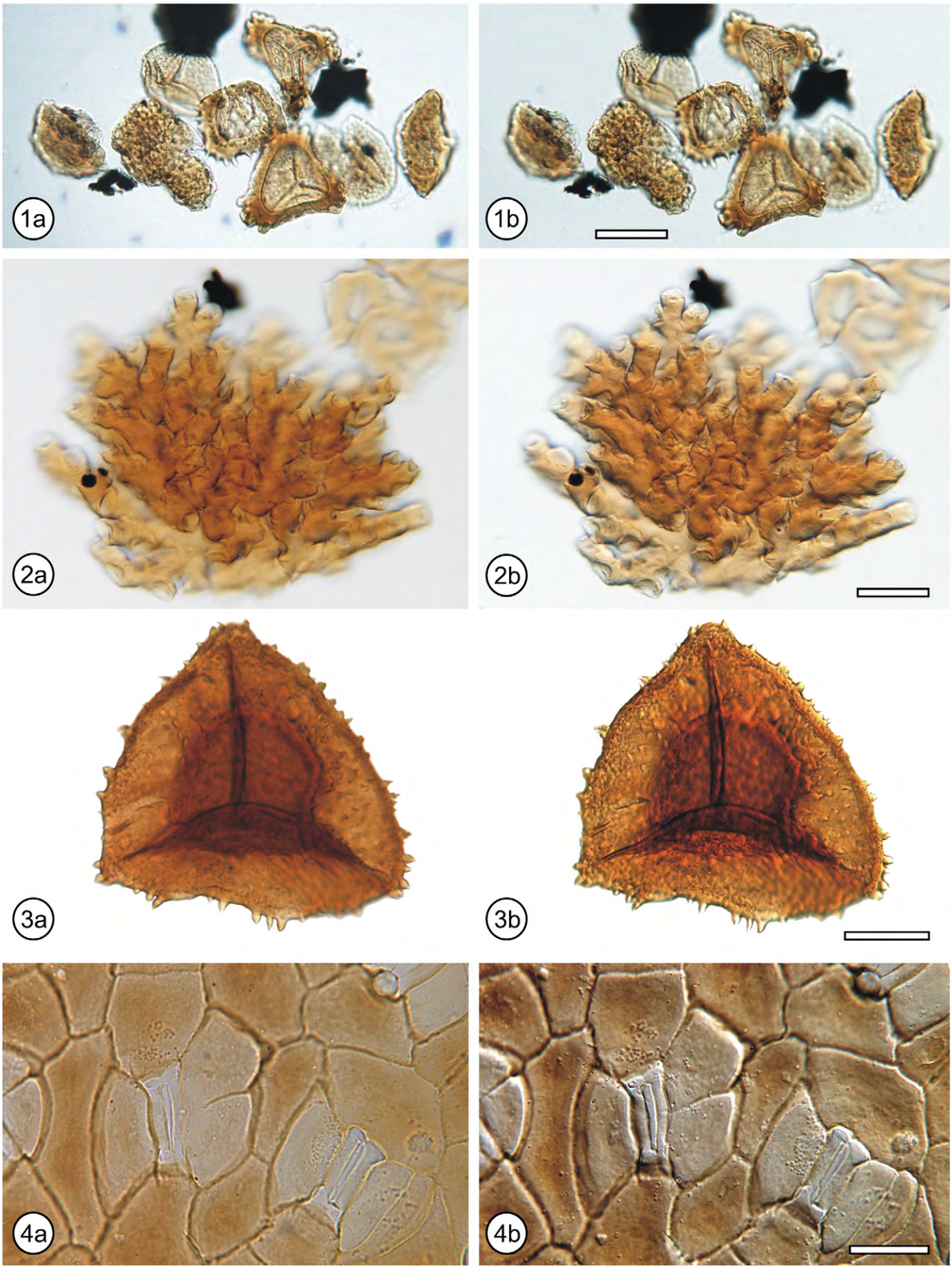
Plate XIII.

1a + 1b. A group of spores from the upper Visean Moscow lignite. The left image 1a) is with an incorrect position of the condenser; this image shows several dark spots (dust particles in the light beam) and an uneven illumination (darker on the left side). The right image (1b) is taken with a correctly adjusted condenser according to Köhler: this results in an evenly illuminated image without dust particles and the spores appear sharper. The condenser diaphragm is identical in both images; no post-exposure editing. Slide PbM 2011/001. Scale bar = 100 μm.

2a + 2b. Images of *Botrycoccus braunii* from the upper Visean Moscow lignite without (2a) and with (2b) Nomarski interference contrast. The apertures of the field and condenser diaphragm settings are identical in both images; no post-exposure editing. Slide PbM 2011/002. Scale bar = 25 μm.

3a + 3b. Images of *Grandispora douglastownensis* from the middle Givetian of the Al Jawf area, Saudi Arabia without (3a) and with (3b) Nomarski interference contrast. The apertures of the field and condenser diaphragm settings are identical in both images. Post-exposure adjustments include adjustment of contrast, saturation and brightness/darkness. Slide PbM 2011/003. Scale bar = 50 μm.

4a + 4b. Stomata of *Dicroidium irnensis* from the Upper Permian Um Irna Formation of Wadi Himara, Dead Sea region, Jordan, without (4a) and with (4b) Nomarski interference contrast. The apertures of the field and condenser diaphragm settings are identical in both images. Post-exposure adjustments include adjustment of contrast, saturation and brightness/darkness. Slide UmIr201U. Scale bar = 50 μm.



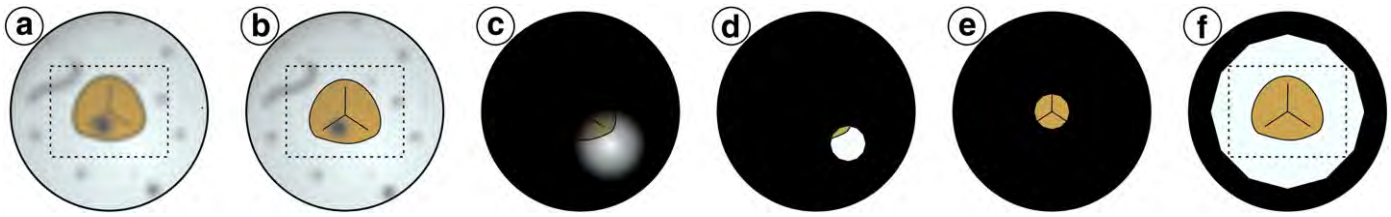


Fig. 16. Successive steps of the correct adjustment of the microscope illumination according to Köhler. a—specimen out of focus, background blurry with dust particles, b—specimen in focus, c—field and condenser diaphragm closed, diaphragm out of focus, d—adjust condenser until diaphragm is sharp, e—condenser centred, f—open field diaphragm until the entire field of image is illuminated; adjust condenser diaphragm for the desired depth of field. Note that part of the field of view outside the image is still dark: the smaller the diaphragm, the better the illumination. Also note that dust particles occurring in the light beam are not longer visible.

(emission) filter (515 nm), giving a bright yellow-golden fluorescence with a dark background for non-fluorescent materials. In epifluorescence microscopy, the centring of the lamp is particularly critical. Also, we advise to darken the room, because the fluorescence is usually rather dark in comparison to the light-microscopic view. This also avoids false light from other sources. As the depth of field decreases with increasing magnification, magnifications should not be too high. Moreover, at higher magnifications, the fluorescence may locally be so intense that images will be overexposed, and structures will appear unclear.

Before starting the actual photo series, first select a piece of cuticle showing an intermediate fluorescence intensity and make a series of images with different exposure times. Choose the best exposure time, and use this setting for all images, regardless whether the fluorescence intensity is weaker or stronger. Because the field of depth is very shallow, particularly at higher magnifications, it may be useful to make several exposures of the same view at successive focusing levels, so as to create a 3D composite by additional image stacking (see Haug et al., 2009a). Depending on the size of the specimen, it will be necessary to photograph a number of parallel transects until the entire object has been covered. Again, when moving the specimen, keep in mind that the individual images overlap each other sufficiently at all sides (20–25%), so that the margins can be erased when individual images are mounted. Also, it is extremely frustrating to realise afterwards that one tiny strip is missing!

The composite image reproduced here on Pl. XVI, 2 was mounted manually (see previous section) and consists of 159 individual images. Even when it is done by hand, mounting images is quickly done, and a large composite image such as this one can be completed in less than a day. Even when individual image files are reduced to less than 15% of their original size, details are still well visible (PL. XVII, 1–2).

6. Digital retouching

Digital image software offers a wide range of useful and effective retouching tools for post-processing. Brightness and contrast adjustments are routinely applied. When retouching colour images, a further simple but very effective method is to slightly reduce the colour saturation after contrast enhancement in order to avoid unnatural colour hues. Many programmes also feature digital dodging-and-burning tools to brighten or darken selected parts of the image. Usually, such tools work well when retouching grey-scale images, but can produce unnatural colour shifts in colour images, which then need to be evened out using colour adjustment tools.

Altogether, it should be kept in mind that nearly all digital retouching tools can only simulate effects that were not initially created during exposure, and that digital manipulating will at some point always result in the loss of original image data. Hence, each original image should be prepared as effectively as possible and require only minimal post-processing. Most digital cameras enable the user to save images in RAW image file formats. These file formats contain the raw image data instead of a readily viewable and printable image, which allows for a fairly wide range of post-processing without losing any quality to be applied before the data are converted to an actual image file.

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Plate XIV. *Dicrodium jordanensis* from the Upper Permian Um Irna Formation in Wadi Himara, Dead Sea region, Jordan. The same pinnule has been photographed with two different methods. 1a is an image of the entire pinnule taken with a high quality stereomicroscope with plan-apo optics using transmitted light and maximum contrast. Post-exposure processing includes further increase of contrast, as well as adjustment of saturation and colour. 1b shows a composite photograph of the same pinnule consisting of 21 images taken with a microscope with a 4× lens. 2a and 2b are enlarged details of the images shown in 1a and 1b. Slide S31U/0002b. Scale bar = 1 mm.

Plate XV. Composite image of the cuticle of the upper pinnule surface of *Dicroidium jordanensis* from the Upper Permian Um Irna Formation in Wadi Himara, Dead Sea region, Jordan. This composite image consists of about 40 micrographs taken with a 10× lens to show sufficient detail. Images were downsized before further processing in order to keep the size of the resulting image file manageable. Slide No. S31U/0003b. Scale bar = 500 μm. (see on page 148)

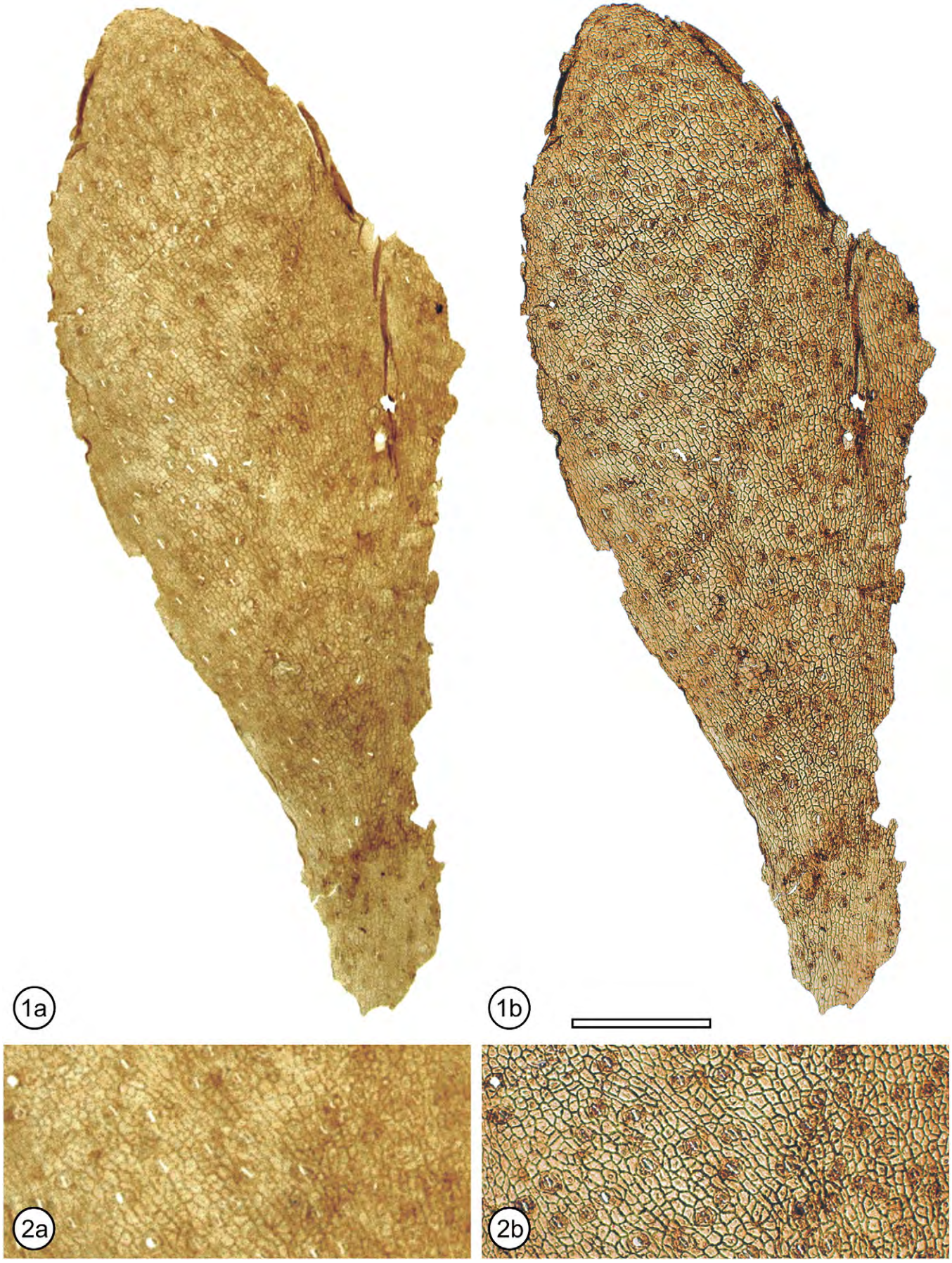

Plate XIV.

Plate XV *(caption on page 146).*

Plate XVI. Pinnules of *Autunia conferta* from the Lower Permian of Veselá, Bohemia, Czech Republic, seem to be well preserved but they easily fall apart during maceration with Schulze's reagent. However, the cuticles show a bright epifluorescence. Specimen PbO 2011/010.

1. Overview. The middle pinnule on the left side was photographed using UV + blue excitation. Scale bar = 1 cm.
2. Composite epifluorescence image of Pl. XVI, 1 consisting of 159 individual images.

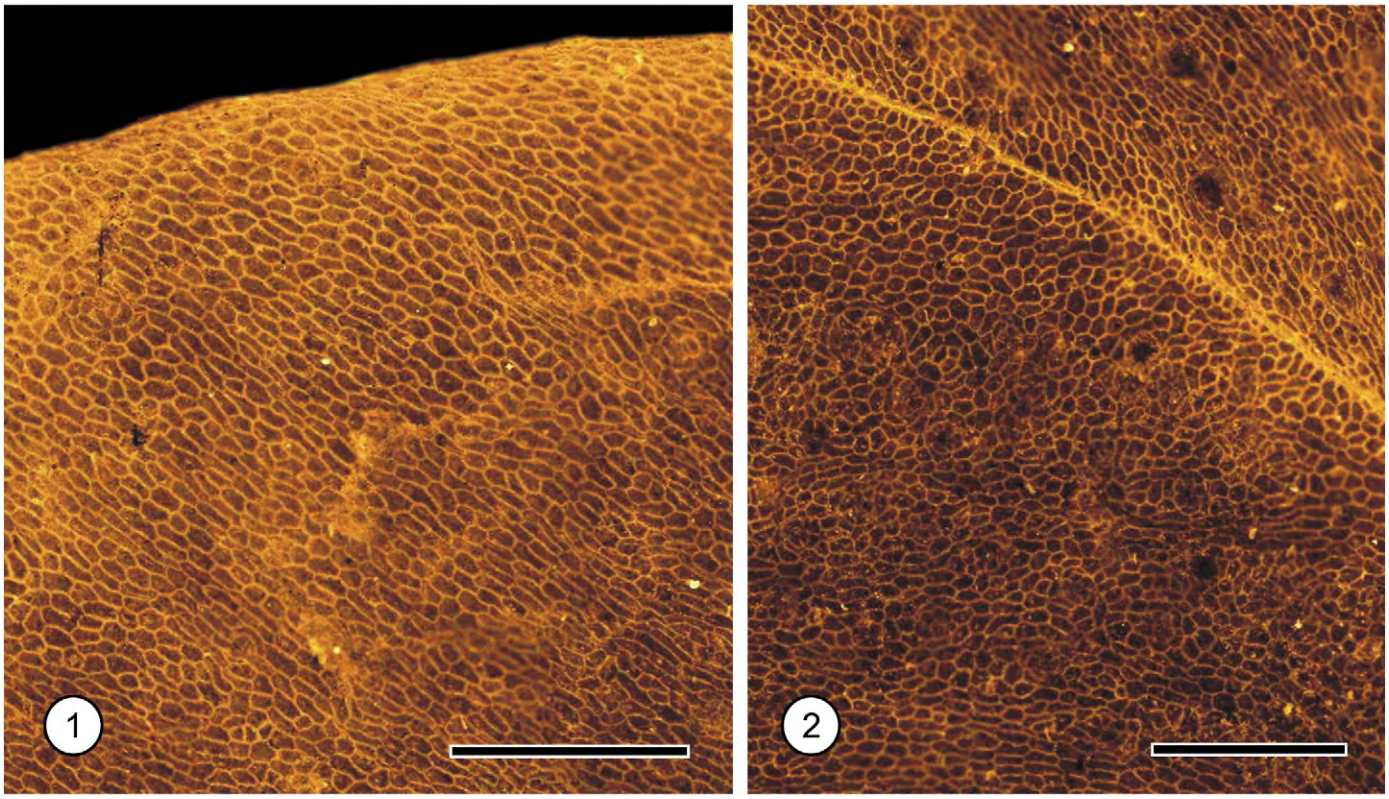

Plate XVII. Details of the composite image shown in Pl. XVII, 2. Specimen PbO 2011/010.

1. Detail showing the apical pinnule margin.
2. Detail showing the midvein (bright fluorescence) and stomata (darker spots).

References

Abu Hamad, A., Kerp, H., Vörding, B., Bandel, K., 2008. A Late Permian flora with *Dicroidium* from the Dead Sea region, Jordan. Review of Palaeobotany and Palynology 149, 85–130.

Allen, R.D., David, G.B., Nomarski, G., 1969. The Zeiss–Nomarski differential interference equipment for transmitted-light microscopy. Zeitschrift für wissenschaftliche Mikroskopie und mikroskopische Technik 69, 193–221.

Barthel, M., 1996. Pflanzenfossilien im rechten Licht. Veröffentlichungen des Museums für Naturkunde Chemnitz 19, 48–62.

Bengtson, S., 2000. Teasing fossils out of shales with cameras and computers. Palaeontologia Electronica 3 (1), 14 pp. http://palaeo-electronica.org/2000_1/fossils/issue1_00.htm (checked December 2010).

Benson, R.H., 1965. Photography of microfossils. In: Kummel, B., Raup, D. (Eds.), Handbook of paleontological techniques. Freeman, San Francisco, pp. 433–446.

Bercovici, A., Hadley, A., Villanueva-Amadoz, U., 2009. Improving depth of field resolution for palynological photomicrography. Palaeontologia Electronica 12 (2) 12 pp. http://palaeo-electronica.org/2009_2/170/index.html (checked December 2010).

Bomfleur, B., Kerp, H., 2010. *Dicroidium* diversity in the Upper Triassic of north Victoria Land, East Antarctica. Review of Palaeobotany and Palynology 160, 67–101.

Bomfleur, B., Kerp, H., Šimůnek, Z., 2007. A composite fluorescence micrograph of a complete pinnule of *Autunia conferta*. In: Elicki, O., Schneider, J.W. (Eds.), Fossile Ökosysteme: Wissenschaftliche Mitteilungen des Instituts für Geologie der TU Bergakademie Freiberg, 36, p. 17.

Boyle, B., 1992. Fossil detail leaps with double polarization. Professional Photographers of Canada 22, 10–12.

Cleal, C.J., Lazarus, M., Townsend, A., 2005. Illustrations and illustrators during the 'Golden Age' of palaeobotany: 1800–1840. In: Bowden, A.J., Burek, C.V., Wilding, R. (Eds.), History of Palaeobotany: Selected Essays: Geological Society London, Special Publications, 241, pp. 41–61.

Davidson, J.P., 2008. A History of Paleontology Illustration. Indiana University Press, Bloomington, IN.

Douglas, R.C., 1965. Photomicrography of thin sections. In: Kummel, B., Raup, D. (Eds.), Handbook of Paleontological Techniques. Freeman, San Francisco, pp. 446–453.

Elovski, V., 1930. Microscopical structure of the coal seam Moshchny, Chernogorski Mines, Minusinsk Basin. Transactions of the Geological and Prospecting Service of U.S.S.R., 4, pp. 5–40.

Ergolskaia, Z., 1930. Description of the microscopical structure of the coal of the Dvukharshinny seam, Chernogorski Mines, Minusinsk Basin. Transactions of the Geological and Prospecting Service of U.S.S.R., 4, pp. 41–81.

Friedrich, W.L., Schaarschmidt, F., 1977. Zwei- und dreidimensionale Fluoreszenzaufnahmen von fossilen Pflanzen. Courier Forschungsinstitut Senckenberg 24, 31–49.

Friedrich, W.L., Schaarschmidt, F., 1979. Auflichtfluoreszenz von fossilen Pflanzen. Zeiss Information 24, 16–18.

Gothan, W., Remy, W., 1957. Steinkohlenpflanzen. Leitfaden zum Bestimmen der wichtigsten pflanzlichen Fossilien des Paläozoikums im rheinisch-westfälischen Steinkohlengebiet. Glück Auf, Essen.

Grauvogel-Stamm, L., 1978. La flore du Grès à Voltzia (Buntsandstein supérieur) des Vosges du Nord (France). Morphologie, Anatomie, Interprétations phylogénique et paléogéographique. Mémoire Sciences Géologiques, 50. Université Louis Pasteur de Strasbourg, Institut de Géologie, pp. 1–225. 34 pl.

Grohne, U., 1957. Die Bedeutung des Phasenkontrastverfahrens für die Pollenanalyse, dargelegt am Beispiel der Gramineenpollen vom Getreidetyp. Photographie und Forschung 7, 237–248.

Haug, J.T., Haug, C., Ehrlich, M., 2008. First fossil stomatopod larva (Arthropoda: Crustacea) and a new way of documenting Solnhofen fossils (Upper Jurassic, Southern Germany). Palaeodiversity 1, 103–109.

Haug, C., Haug, J.T., Waloszek, D., Maas, A., Frattigiani, R., Liebau, S., 2009a. New methods to document fossils from lithographic limestones of southern Germany and Lebanon. Palaeontologia Electronica 12 (3). http://palaeo-electronica.org/2009_3/193/index.html (checked December 2010).

Haug, J.T., Haug, C., Maas, A., Fayers, S.R., Trewin, N.H., Waloszek, D., 2009b. Simple 3D images from fossil and recent micromaterial using light microscopy. Journal of Microscopy 233, 93–101.

Howell, J., 1977. Photography of low-contrast fossils. Journal of Paleontology 51, 419–420.

Keller, C. (Ed.), 2008. Brought to light—Photography and the invisible 1840–1900. Yale University Press, New Haven, CT.

Kerp, J.H.F., 1983. Aspects of Permian palaeobotany and palynology. I. *Sobernheimia jonkeri* nov. gen., nov. sp., a new fossil plant of cycadalean affinity from the Waderner Gruppe of Sobernheim. Review of Palaeobotany and Palynology 38, 173–183.

Kerp, J.H.F., 1988. Aspects of Permian palaeobotany and palynology. X. The West- and Central European species of the genus *Autunia* Krasser emend. Kerp (Peltaspermaceae) and the form-genus *Rhachiphyllum* Kerp (callipterid foliage). Review of Palaeobotany and Palynology 54, 249–360.

Kerp, H., Krings, M., 2003. Kutikularanalytische Befunde zur Abgrenzung der *Odontopteris minor* f. *zeilleri* Potonié von *Odontopteris reichiana* Gutbier. Courier Forschungsinstitut Senckenberg 241, 31–42.

Kerp, H., Poort, R., Swinkels, H., Verwer, R., 1989. A conifer-dominated flora from the Rotliegend of Oberhausen (Saar-Nahe area). Courier Forschungsinstitut Senckenberg 109, 137–151.

Kerp, J.H.F., Poort, R.J., Swinkels, H.A.J.M., Verwer, R., 1990. Aspects of Permian palaeobotany and palynology. IX. Conifer-dominated Rotliegend floras from the Saar-Nahe Basin (?Late Carboniferous–Early Permian; SW-Germany) with special reference to the reproductive biology of the earliest conifers. Review of Palaeobotany and Palynology 62, 205–248.

Kier, P.M., Grant, R.E., Yochelson, E.L., 1965. Whitening fossils. In: Kummel, B., Raup, D. (Eds.), Handbook of Paleontological Techniques. Freeman, San Francisco, pp. 453–456.

Köhler, A., 1893. Gedanken zu einem neuen Beleuchtungsverfahren für mikrophotographische Zwecke. Zeitschrift für wissenschaftliche Mikroskopie 10, 433–440.

Krings, M., Kerp, H., 1998. Epidermal anatomy of *Barthelopteris germarii* from the Upper Carboniferous and Lower Perrmian of France and Germany. American Journal of Botany 85, 553–562.

Krings, M., Kerp, H., 1999. Morphology, growth habit and ecology of *Blanzyopteris praedentata* (Gothan) nov. comb., a climbing neuropteroid seed fern from the Stephanian of Central France. International Journal of Plant Sciences 160, 603–619.

Krings, M., Kellogg, D.W., Kerp, H., Taylor, T.N., 2003. Trichomes of the seed fern *Blanzyopteris praedentata*: implications for plant–insect interactions in the Late Carboniferous. Botanical Journal of the Linnean Society London 141, 133–149.

Massalongo, A.B., 1859. Specimen photographicum animalium quorundam plantarumque fossilium Agri Veronensis./Saggio fotografico di alcuni animali e piante fossili dell Agro Veronese. Franchini, Verona, 101 pp., 40 photographic plates.

Nomarski, G., 1955. Microinterféromètre différentiel à ondes polarisées. Journal de Physique et Le Radium 16, 9S–16S.

Padawer, J., 1968. The Nomarski interference-contrast microscope—an experimental basis for image interpretation. Journal of the Royal Microscopical Society 88, 305–349.

Pott, C., Krings, M., Kerp, H., 2007. A surface micro-relief on the leaves of *Glossophyllum florinii* (?Ginkgoales) from the Upper Triassic of Lunz, Austria. Botanical Journal of the Linnean Society London 153, 87–95.

Rasetti, F., 1965. Photography of fossils. In: Kummel, B., Raup, D. (Eds.), Handbook of Paleontological Techniques. Freeman, San Francisco, pp. 423–430.

Rayner, R.J., 1992. A method of improving contrast in illustrations of coalified fossils. Palaeontologia Africana 29, 45–49.

Rees, P.M., 1993. Dipterid ferns from the Mesozoic of Antarctica and New Zealand and their stratigraphical significance. Palaeontology 36, 637–656.

Reinsch, P.F., 1881. Neue Untersuchungen über die Mikrostruktur der Steinkohle des Carbon, der Dyas und Trias. Beiträge zur Aufhellung des Ursprunges und der Zusammensetzung dieser Mineralkörper, sowie zur Kenntniss des einfachsten Pflanzenlebens der Vorwelt. T.O. Weigel, Leipzig.

Reinsch, P.F., 1884. Micro-Palaeo Phytologia Formationis Carboniferae. Iconographia et Dispositio Synoptica Plantularum microscopicarum omnium in venis Carbonis Formationis Carboniferae hucusque cognitarum, eorumque illis proximorum corpusculorum natura vegetabilica non incerta, quae inveniuntur et in venis carbonis et in stratis Formationum infra supraque Carboniferam sequentium. Theodor Krische, Erlangen. London, Bernard Quaritch.

Remy, W., Remy, R., 1959. Pflanzenfossilien. Ein Führer durch die Flora des limnisch entwickelten Paläozoikums. Akademie-Verlag, Berlin.

Remy, W., Remy, R., 1977. Die Floren des Erdaltertums. Einführung in Morphologie, Anatomie, Geobotanik und Biostratigraphie der Pflanzen des Paläophytikums. Glück Auf, Essen.

Rousseau, L.F.E., Devéria, A., 1853. Photographie zoologique ou représentation des animaux rares des collections du Muséum d'histoire naturelle. Masson et Cie, Paris. Gambart & Co., London.

Rowe, N.P., 1999. Macrophotography. In: Jones, T.P., Rowe, N.P. (Eds.), Fossil Plants and Spores—Modern Techniques. Geological Society, London.

Samuelsson, K.E., 1965. Photomicrography of Recent and fossilized pollen. In: Kummel, B., Raup, D. (Eds.), Handbook of Paleontological Techniques. Freeman, San Francisco, pp. 626–636.

Schaarschmidt, F., 1973. Pflanzenfossilien in ungewöhnlichem Licht. Natur und Museum 103, 247–253.

Schaarschmidt, F., 1982. Präparation und Untersuchung der Eozänen Pflanzenfossilien von Messel bei Darmstadt. Courier Forschungsinstitut Senckenberg 56, 59–77.

Staggs, S., 2005. Crime Scene and Evidence Photographer's Guide 2nd edition. Staggs Publishing, Wildomar, CA.

Stur, D., 1885. Die Carbon-Flora der Schatzlarer Schichten. Abtheilung 1: Die Farne der Carbon-Flora der Schatzlarer Schichten. Abhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt 11 (1), 1–418.

Stur, D., 1887. Die Carbon-Flora der Schatzlarer Schichten. Abtheilung 2: Die Calamarien der Carbon-Flora der Schatzlarer Schichten. Abhandlungen der Kaiserlich-Königlichen Geologischen Reichsanstalt 11 (2), 1–240.

Van Gijzel, P., 1967. Autofluorescence of fossil pollen and spores with special reference to age determination and coalification. Leidse Geologische Mededelingen 50, 263–317.

Van Gijzel, P., 1977. Die Fluoreszenz-Mikroskopie einiger Pflanzenfossilien. Courier Forschungsinstitut Senckenberg 24, 92–100.

Van Gijzel, P., 1979. Manual—Techniques and Geological Application of Fluorescence Microscopy. Workshops October 29–November 2, 1979, Dallas, Texas. AASP, Dallas. 55 pp.

Sternberg, K.M. von, 1820. Versuch einer geognostisch-botanischen Darstellung der Flora der Vorwelt, Volume I, Part 1. F. Fleischer, Leipzig. E. Brenck'sche Witwe, Regensburg.

Wagner, R.H., Álvarez-Vázquez, C., 2010. The Carboniferous floras of the Iberian Peninsula: a synthesis with geological connotations. Review of Palaeobotany and Palynology 162, 239–324.

Warren, J.C., 1854. Remarks on Some Fossil Impressions in the Sandstone Rocks of Connecticut River. Ticknor and Fields, Boston. 54 pp.

Whittington, H.B., 1965. Photography of small fossils. In: Kummel, B., Raup, D. (Eds.), Handbook of Paleontological Techniques. Freeman, San Francisco, pp. 430–433.

Wilson, L.R., 1962. Plant microfossils from the Flowerpot Formation, Greer County, Oklahoma. Oklahoma Geological Survey Circular 49, 1–50.

Zernicke, F., 1942a. Phase contrast, a new method for the microscopic observation of transparent objects. Part I. Physica 9, 686–698.

Zernicke, F., 1942b. Phase contrast, a new method for the microscopic observation of transparent objects. Part II. Physica 9, 974–986.