Scanning Rocks for Data

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Insects represent one of the most diverse groups of organisms living on our planet. What is often overlooked is their magnificent fossil record, dating to at least the Devonian era (>400 mya [million years ago]; Grimaldi and Engel 2005). Fossil insects represent a unique source of morphological insight that is often passed over because of the difficulty in locating certain fossils, the expense of shipping fossils as loan material because of weight and fragility, and the expense of traveling to each museum with holdings of a particular group. In addition, methods of observing and documenting the morphological features of fossil insects can be subtle and are not widely discussed. To this end, we propose two complementary methods, one traditional (macro photography) and the other more novel (flatbed scanning), to digitally document insect compression fossils.

Flatbed scanners have been used for imaging living organisms, most notably for plants and plant pests (McConnell 2006, Skaloudova et al. 2006), but also for extant insects, particularly dragonflies (Mitchell and Lasswell 2000). Because our research focuses on the essentially 2D compression fossils of Holodonata (the group containing extant and fossil dragonflies and damselflies), scanning lends itself nicely to this task.

One challenge of imaging fossils, especially holodonates, is their large size (*Meganeuropsis permiana*, had a wingspan of ~710 mm). Many flatbed scanners are capable of making scans of 320 mm × 230 mm and can accommodate almost all large fossil insects. Because these specimens have not been pinned and crammed into a unit tray for storage, many have multiple and often large labels associated with them. It is not uncommon for some specimens to be accompanied by folded letters from prominent scientists, containing important historical observations; these are precious artifacts in their own right. Some collections curate small fossils in the same box or unit tray, according to a given taxon or geological formation; and many compression fossils have two halves, each with important morphological details. The flatbed scanner is a wonderful tool that can usually capture all of this information (e.g., multiple labels, letters, both halves of the specimen) in a single scan and produce an instant image that can be used to document the entire contents of each unit tray or box in high resolution.

Digital macro photography is a complementary method for documenting compression fossils. Because the rock matrix surrounding fossil specimens may be reflective or similar in color to the fossil, the ability to manipulate lighting often makes macro photography indispensable. The rock matrix surrounding a fossil may not allow for the fossil to lie flat against that scanner, producing a challenge for a flatbed scanner's shallow depth of field.

Materials and Methods

Collections Studied. To date, we have digitized the holodonate type holdings from three major museums, the Paleoentomological Institute (Moscow), the Natural History Museum (London), and the Museum of Natural History (Paris). Each museum has outstanding fossil holdings that are exceptional for fossil insects. Taken together, these collections have unmatched holodonate holdings dating back well into the Carboniferous and up to the Oligocene eras, a period of more than 300 million years.

Scanning. Scanning fossil material must be done carefully, not only because the fossils may be fragile and irreplaceable, but also because if one is not careful, the scanner will need to be replaced. Typically, all the contents of a unit tray or box and all associated text data (e.g., from labels, identification) can be placed on the scanner. If specimens are small, multiple fossils may be placed on the scanner together.

Once in place, we take two or three scans of each fossil. Step 1: A scan at 180–300 dpi documents the entire holdings of a single curated box or unit tray. Step 2: A second scan of each fossil is made at 1,200–2,400 dpi, depending on the size of the fossil (this step is repeated for the complementary half of the compression fossil, if one exists). Step 3: The specimen is scanned at <2,400 dpi. This step is usually reserved for small specimens or structures that are important to our research (e.g., the nodus or wing articulation). All scans were made at 48-bit color under standard settings set by the software.

We tested four scanners: the CanoScan 9950F, the CanoScan 8800F, the CanoScan LiDE 600F, and the Epson 3200. All of these machines scan at a resolution of up to 4,800 × 9,800 dpi (except for the Epson 3200, which scans at up to 1,200 × 3,200 dpi) and are meant to produce high-quality

scans of photonegatives and photographs. Each scanner operated equally well for our purposes, with the exception of the CanoScan LiDE 600F. The LiDE 600F is a small, lightweight scanner that draws its power directly from the computer and is designed to be carried in a briefcase. For these reasons, it was attractive to our research. During testing, this scanner was only capable of scanning documents because its depth of field appeared to be much <2 mm.

An advantage of using high-end scanners is that scanning times are very short. Although scanning time is dependent on the size and resolution of the scan, scans taken at 180–300 dpi take <15 seconds. The higher resolution scans (1,200 dpi and above) can take several minutes. Multiple scans may be set up at once by creating multiple scanning boxes using the cursor and mouse and setting the dpi for each scanning box separately. At this point, the user can simply initiate the scan and walk away for some 10 min. Additionally, by scanning directly into Photoshop, images can be immediately altered and saved in several file formats. For our purposes, files are stored as TIFFs.

Specific materials are required for a successful scanning trip. Besides checking that all electronic equipment is capable and adequately equipped (e.g., with adapters) to operate properly in a foreign country, there are some materials that make the process easier, faster, and safer.

Most fossils are not heavy enough to break or crack the glass of a scanner, but they can scratch it, thereby compromising future scans. This is easily overcome by placing a thin, clear sheet of plastic, such as a standard overhead projector sheet, on top of the scanner's glass bed and under the fossil. It also helps to have a chamois cloth ready to wipe away any dust buildup on the plastic sheet or the flatbed scanner.

Another indispensable tool is a broad rubber band (~5 mm wide). By positioning the rubber band on its side, it is possible to prop fossils up so that they lie in the same plane as the glass bed. The rubber band also keeps a good "grip" on the overhead sheet, whereas paper wedged beneath a fossil tends to slip. A thin plastic or paper ruler, placed on the glass bed, provides an accurate source of scale for the image. Some photo manipulation software packages have the ability to provide size measurements directly from images as long as they are scanned to 100% actual size. However, as a quick reference (and as it was our intention to disseminate these images over the Web in different sizes and file formats), a ruler to provide scale scanned with each image served our needs and was efficient. A black cloth was laid over the fossil(s) on the scanner bed to cut down on interference from outside light. The cloth also serves as a paperweight for the labels and other associated papers, keeping them in close contact with the glass bed.

A laptop computer is needed, to drive the scanner and run photo manipulation software. Along with the laptop, we used several small-profile, USB-powered, travel-friendly external hard drives to back up all images. All files were backed up each day on each hard drive, and the files generated from that day were erased from the laptop. We generated an average of 20 GB of images from each trip, and it was simply not possible to leave this amount of data on our desktop.

Macro Photography. We used a Nikon D70 digital SLR (6.1 megapixel) fitted with an AF Micro Nikkor lens (105mm/2.8) and a MacroLume TTL Promaster ring flash to take digital photographs for each fossil. To provide greater contrast between the fossil and rock matrix, we used a single external halogen light source to provide oblique illumination.

Each fossil was photographed at least twice. The first image was taken to document the fossil and the rock in which it was contained and as a backup to the scanned material. The second image was as a greatly magnified shot to document fossilized structure(s). Because some fossils were very large, images of the wing were taken in sections. Generally, we took 5–6 images for each wing >75 mm. Images were taken in RAW format and later transformed to TIFF files using Photoshop. A grey or black cloth was used as background and for positioning of the fossil so that the specimen was as horizontal as possible during photography. The cloth proved better than grey card stock because it could be fitted around the fossil, allowing for better manipulation of light.

Results

We found that imaging insect fossils with a flatbed scanner has several advantages. Scanning provides the opportunity for high-resolution images of the entire specimen, even when the specimen is large. The entire contents of a curated box or unit tray (e.g., multiple fossils and labels) can be scanned all at once. A scanner can be programmed to scan automatically, thereby giving the researcher time to prepare additional fossils for scanning. This method of imaging uses direct light to evenly illuminate the subject and preserve details that otherwise might be lost.

The disadvantages of scanning include traveling with heavy, bulky equipment (e.g., a scanner and laptop computer); a shallow depth of field (~5 mm); a relatively long scan time (when compared with a digital camera); and the production of large files (3–200 MB depending on scan size and resolution). It is also a challenge to image a reflective rock matrix with the direct lighting of a scanner.

Our digital images produced using scanning and digital photographic techniques will be available to the scientific community for study on the morphological image database MorphBank. They will also be hosted at Odonatacentral.com, the world's largest Web site devoted to Odonata, for use by the public and educators.

Discussion

The use of flatbed scanners and macro photography in imaging insect fossils is complementary and effective. The two methods differ most in three

Fig. 1. Comparison of direct vs. oblique light: (a) the image captured from a scan with only direct illumination of the fossil; (b) an image taken with a digital camera while under oblique light. The white box denotes an area of the image where sharp focus was lost using macro photography due to the large size of the wing.

main aspects: lighting (direction of illumination), depth of field, and ability to minimize light reflected from the rock matrix surrounding fossils.

We used two methods of illumination to image the insect compression fossils, direct and oblique lighting. Each can be used to complement the other because they often can accentuate different features of a subject.

Direct lighting can reduce or eliminate artifacts caused by reflections or shadows, thereby producing an exact representation of the subject. In direct lighting, light is directed onto the subject from the same direction as an "eye" viewing it, thereby illuminating the subject evenly. The difficulty of using direct lighting is that is can be too harsh to clearly show subtle differences in the texture of a material.

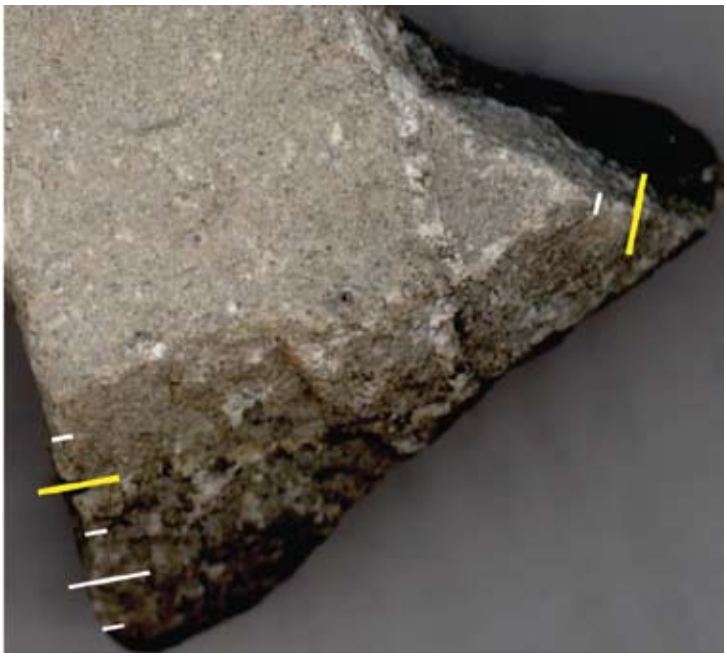

Fig. 2. Demonstration of the depth of field when using a CanoScan 9950F flatbed scanner. Each bar denotes 2.5 mm, and the yellow bar marks the deterioration of the depth of field.

Oblique lighting often produces more drama in an image by creating shadows that demark changes in the surface texture of a fossil, thereby adding more contrast. With this kind of illumination, light is directed toward the subject at an oblique angle (i.e., from the side) to create slight shadows that accentuate subtle features of the subject's surface. This is perhaps most dramatically illustrated in the corrugations of the odonate wing (compare Figs. 1a and b). The difficulty of using oblique illumination when imaging fossil insects is that the generated shadows can partially or completely obscure other features that are present.

Scanners project only direct light on the scanned object, resulting in images that capture all structures of the wing, particularly venation, in a very clear image (Fig. 1a). Macro photography provides the flexibility to adjust the direction of the light source (e.g., direct and/or oblique illumination). The use of oblique lighting accentuates the topography of the wing by creating shadows (Fig 1b). Having both images, one that comprehensively documents details of the wing (e.g., wing venation) and the other that accentuates surface topography, are ideal and necessary complements from which to study morphological characters.

Depth of field is the biggest difference between imaging fossils with a scanner or photography. The scanners we used had a depth of field of ~5 mm, but began to quickly deteriorate at ~3.5 mm (Fig. 2). Depth of field is only an issue when a fossil is sunk within the rock matrix (i.e., it is not in the same plane as or resting close to the scanner's glass bed). The issue that arises because of the scanner's depth of field is that portions of the wing that are set within the rock matrix at >3.5mm begin to lose focus (see white boxes in Fig. 3a). The combination of a fossil embedded within the rock matrix and the direct light produces scans that are "flat" (compare the scan in Fig. 3a with the photograph in Fig. 3b). Additionally, keeping the entire fossil in focus when manually photographing fossils, especially when large (see box, Fig 1b), is difficult. As long as the wing is flush with the surface of the rock face, as is often the case, the scanner will keep the entire wing surface in focus (Fig. 1a).

Reflective rock matrixes can complicate the imaging of insect compression fossils. Certain types of rock matrixes that contain fossils can be reflective because of their light color or mineral composition. An increased amount of reflective light obscures subtle features, especially those that are light in color. Macro photography has the advantage in that the amount and direction of illumination can be adjusted or the fossil itself can be moved to an angle at which less light is reflected back toward the lens, resulting in less bleached images. The ability to manipulate the method of illumination and the orientation of the fossils allows for capturing greater contrast between the fossil and its surrounding matrix. Multiple images complement each other as the manipulation usually results in the ability to photograph only a portion of a fossil.

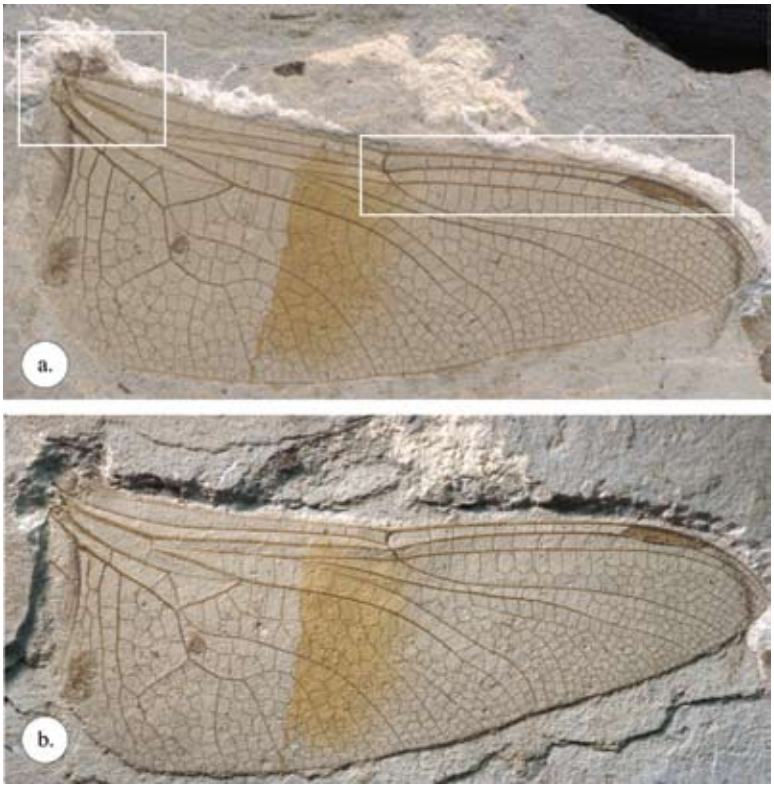

Fig. 3. Comparison of depth of fields: (a) scan of a fossil that has portions of the wing embedded in the rock matrix (i.e., wing regions are not in the same plane as the scanner bed). The white boxes highlight areas of the wing where sharp focus is lost due to a shallow depth of field. (b) A digital photograph of the same fossil showing improved depth of field resulting in sharper focus throughout the entire wing.

Conclusions

We discuss using the flatbed scanner and macro photography as two methods for imaging insect compression fossils. Both methods represent viable cost-effective, complementary imaging techniques. Scanning represents an extremely low-cost, high-throughput solution to digitizing insect fossil holdings (at least type specimens), and we encourage its use. Fossils can contribute a great deal to the study of evolution, and image databases are a valuable tool for storing and disseminating image data to the scientific community. Our hope is that the use of these simple techniques for imaging fossils in conjunction with the use of online databases for the Holodonata will catalyze research on this and other groups of insects.

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