Palaeoentomology 008 (5): 487–490
https://www.mapress.com/pe/

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ISSN 2624-2826 (print edition)
PALAEOENTOMOLOGY
ISSN 2624-2834 (online edition)

https://doi.org/10.11646/palaeoentomology.8.5.5
http://zoobank.org/urn:lsid:zoobank.org:pub:84730FDA-1A52-4357-86E0-697D547E50B6

Merging part and counterpart images of compression fossils

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While examining rich insect collections from the Lower Permian Chekarda locality in the Cis-Urals region of Russia, preserved at the Paleontological Institute (PIN) in Moscow, I noticed that dark patches, representing fragments of fossilized cuticle upon a lighter rock matrix, on the part and the counterpart of one fossil often appeared complementary and could be fitted together like a jigsaw puzzle. The phenomenon is well familiar to those who study thin compression fossils. Insects, for example, occasionally become compressed by sediment to such a state that the multiple cuticular layers of their bodies—opposite body sides, overlapping wings, legs, and other appendages—all become fused into a single film of fossilized cuticle. Then, a blow of the rock hammer fractures this film in such a way that some of its fragments become exposed upon the part and others upon the counterpart. I attempted to combine such part and counterpart images into more complete composites and in this way I was able to interpret many poorly preserved specimens, which otherwise would be left out of the study, and, moreover, to see and understand morphological structures of crucial importance, which otherwise would be overlooked. The results of my palaeoentomological study will be published elsewhere, but my success in superposition of part and counterpart images warrants a separate, brief publication on the method itself. Undoubtedly the idea must have occurred to many. Merged composites of part and counterpart images and descriptions of the implemented merging techniques have been published as part of larger studies (*e.g.*, Haug *et al.*, 2009; Haug & Haug, 2013). Yet, I believe the method deserves a dedicated discussion. It has some limitations, which confine the scope of its use, but in some cases it may help visualize poorly preserved, badly fragmented specimens, which may otherwise remain uninterpretable. Therefore, the goal of the present note is to describe a simple method of part-counterpart (PCP) image merging and discuss its pitfalls and limitations. The images were processed manually using either of two computer graphics editors, the proprietary Adobe Photoshop and the free open-source GIMP. In this form, the technique is available to virtually anyone. On the other hand, its computer automation appears to be a realistic goal.

Source images

1) The imaged insect fossils came from the collection of Borissiak Paleontological Institute of the Russian Academy of Sciences (PIN) in Moscow. Light images at a resolution of 4908 × 3264 pixels, 16-bit, TIFF, were taken with a Nikon DS-Ri2 digital camera mounted on a Nikon SMZ25 stereomicroscope. Every attempt was made to orient the imaged surfaces as horizontally as possible. To avoid shadows and glare, the specimens were evenly illuminated and covered with alcohol; the layer of liquid additionally makes the thin fossilized cuticle, and the thin mineral crusts occasionally obscuring it, partially transparent. 2) Scanning electron micrographs of a pair of uncoated specimens were taken at PIN on a Tescan Vega2 (Brno, Czech Republic) scanning electron microscope operated in a low-vacuum mode. Images were obtained with a backscattered-electron (BSE) detector, which was fully inserted into the specimen chamber to eliminate shadows. 3) Images from literature. An additional pair of source images were copied from a pdf version of a published paper (Jepson *et al.*, 2011). For processing, these images were upsampled to a resolution of 3376×1488 pixels.

Software

Images were processed with Adobe Photoshop CS64, version 13, or, alternatively, with GIMP 2.10.38. Both programs implement the same blending algorithms and produced the same results. The following description refers to Adobe Photoshop.

Superimposition

The pair of images were placed on top of one another as separate layers of one image file. I then used standard tools to adjust the upper image to the same magnification, orientation, contrast, brightness, and coloration as the lower one. Achieving a perfect superimposition is usually the hardest part. During this step, I found it most convenient to change the blending mode of the upper layer from *Normal* (default) to *Darken*. Among the two superimposed pixels this algorithm shows only the darker one (Adobe Photoshop Help; GIMP User Manual). This works quite well when the fossil fragments to be fitted are darker than the rock, which seems to be the most common case. If it is otherwise, one can use the *Lighten* blending mode for the same purpose. Superimposition was optimized using Free Transform tools. Occasionally—apparently when the imaged surfaces deviated from the common horizontal plane—the upper image had to be

Submitted: 28 May 2025; accepted by D.-Y. Huang: 7 Oct. 2025; published: 31 Oct. 2025

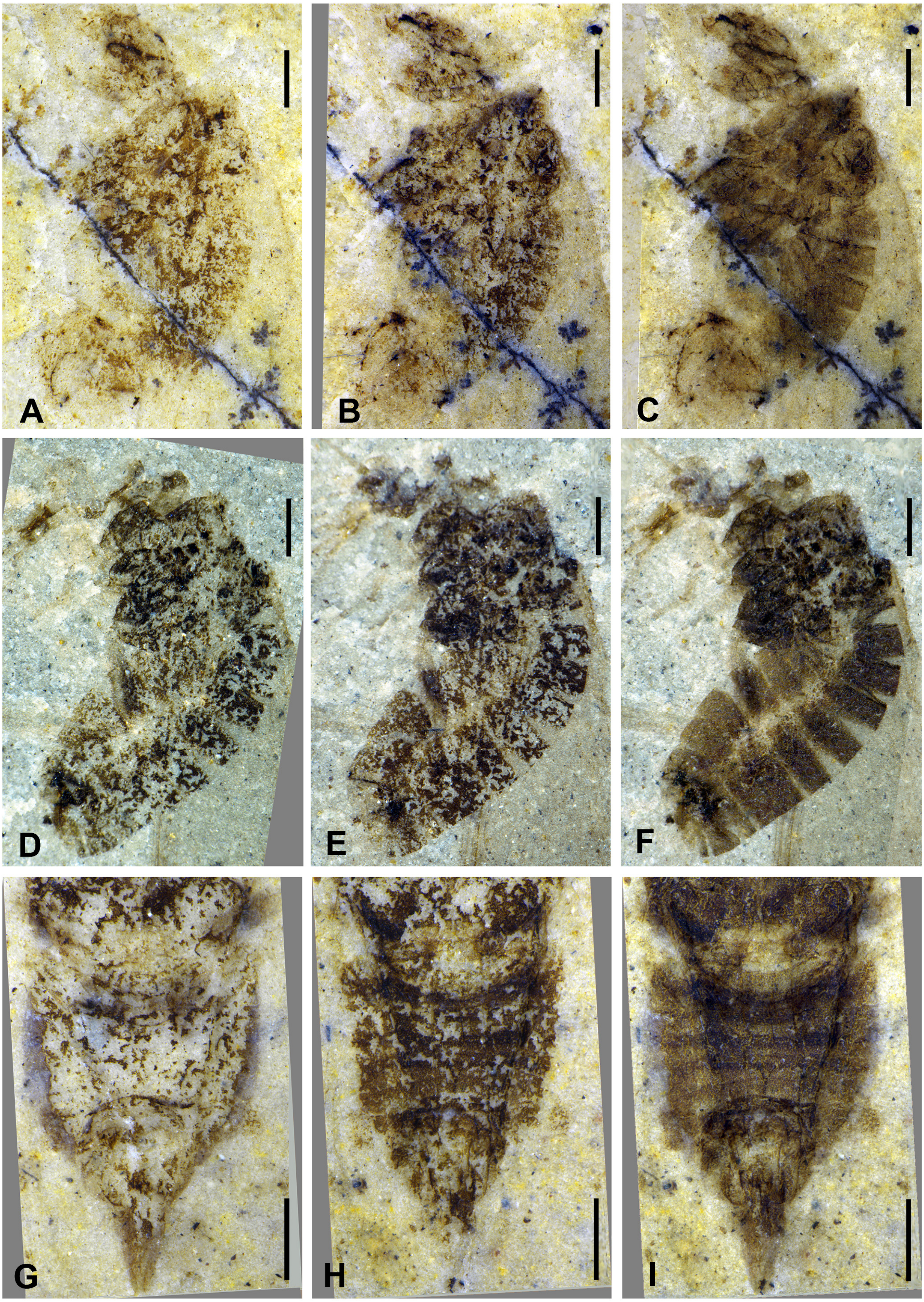

FIGURE 1. Examples of PCP merging of light images: insects from the Lower Permian of Chekarda. **A**–**C**. Psocoptera (Insecta), PIN 4987/1023, preserved in lateral orientation. **A**, Part. **B**, Counterpart (mirrored). **C**, Composite. **D**–**F**, Psocoptera (Insecta), PIN 4987/1024, preserved in lateral orientation. **D**, Part. **E**, Counterpart. **F**, Composite. **G**–**I**, Ingruidae (Insecta, Hemiptera), PIN 4987/1025, posterior thorax and abdomen, preserved in dorsoventral orientation. **G**, Part. **H**, Counterpart (mirrored). **I**, Composite. Scale bars: 0.5 mm.

slightly distorted or warped locally, using *Warp* or *Puppet Warp* tools, to achieve a better superimposition.

Final blending

Once a perfect superimposition has been achieved, one has a choice among numerous blending modes available in the editor (Adobe Photoshop Help; GIMP User Manual) to produce the final composite image. Among these, only *Darken* and *Multiply* are worth consideration. Both are potentially useful, but *Multiply* has the advantage of combining visual information from both layers at every pixel, rather than keeping only the darker pixels. In the ideal case, *i.e*., when the part and the counterpart display strictly non-overlapping, complementary fragments, *Darken* does the job perfectly (if the fragments are lighter than the rock, use *Lighten* instead). Advantageously, this method does not decrease the overall brightness of the resulting image in comparison to the original pair. However, more usually, some overlapping areas are also present (see Discussion). In such cases, the *Multiply* blending algorithm makes visible details of both superimposed surfaces, which makes it the first-choice method. Disadvantageously, *Multiply* produces the result significantly darker than either of the source images. Therefore, once the two layers have been merged into a composite one, its brightness has to be increased using conventional tools. Note that, with both algorithms, the resulting composite is the same whichever of the two source images was on the top.

The technique is essentially similar to the one described by Haug and Haug (2013) but is simpler since both the alignment and the subsequent blending of images are performed in one computer program.

Figure 1 and Figures S1–S3 showcase selected successful results of PCP merging. In all the examples, the composite image is less fragmented and displays morphology not easily seen in either of the two original images. Such are, for example, the distinct thoracic and abdominal sclerites in Fig. 1, Fig. S1, and Fig. S3 and distinct basal parts of the costal wing veins in Fig. S2. In particular, the composite shown in Fig. 1F shows the basal abdominal sternites not distinguishable in the source images (Fig. 1D, E). The Fig. 1I gives a clearer representation of the structure of the abdominal genital segments, important for sexing and classification of the specimen, than its source images (Fig. 1G, H). Merging previously published images (Fig. S2) or scanning electron micrographs (Fig. S3) also produced informative composites.

Discussion. The potential of PCP merging as an attempt to at least partially reassemble visual information fragmented between the part and the counterpart is obvious. Its disadvantages and limitations, which explain why this simple technique is not widely used, need a closer examination. Potential users must not be too disappointed if a PCP composite has no added value, which can never be guaranteed, or turns out harder to interpret than the source images. The two main potential issues are discussed next. 1) The part and the counterpart naturally represent fragments of two opposite sides of the compressed object. If these have disparate characteristics, the composite will show a bizarre mixture of both. For example, the ventral and the dorsal sides of the stylized bug in Fig. S4 have different coloration and morphology. The PCP composite, therefore, shows a mosaic of these features (Fig. S4E). 2) The part and the counterpart often bear fragments that overlap during superimposition. Such overlapping fragments result from the split having propagated through the middle of the fossil. Therefore, the thinner the fossil, the less often such fragments must occur. Conversely, with thicker fossils these will predominate. Applying a blending algorithm to such fragments will produce unnaturally looking areas.

The above discussion suggests that the useful application of PCP merging is limited to extremely thin, nearly two-dimensional compression fossils with identical opposite sides (including thin bilateral fossils preserved in a strictly lateral position). Such common and important fossils as insect wings are likely to fall in that category. Additionally, the pitfalls of PCP merging can be somewhat mitigated in those cases when the fragments are partially transparent, which is often the case with insect cuticles. Due to such transparency, each fragment of the PCP composite shows details of both opposite surfaces, which improves representation of the overall morphology (compare Fig. S4E, H). Users may feel uncertain as to whether PCP composites can be used as illustrations instead of their source images. Perhaps the best practice would be treating such composites as the author's personal interpretation, like drawings, and publishing these alongside the source images or, alternatively, limiting their use exclusively to preparatory stages of the study. Like with a jigsaw puzzle, a good fit between the part and the counterpart over the entire imaged area strongly limits the chance of introducing a human error into the resulting composite. Nevertheless, a caution needs to be exercised, especially when local distortion or warping had been used to improve superposition.

Manual PCP blending described here is easy enough to try—and to give up if no meaningful result was produced. Still, obtaining a perfect superimposition of two images can be tedious. I am not aware of any software to perform the task automatically. There is no doubt that such software can be created, for example using methods based on artificial neural networks and artificial intelligence.

Acknowledgements

For helpful discussion and encouragement, I thank members of the Arthropoda Lab of the Paleontological Institute: Dmitri Shcherbakov, Alexander Rasnitsyn, and Elena Lukashevich, who additionally provided the dipteran specimens. I also thank Matus Hyžný (Comenius University, Bratislava, Slovakia) and two anonymous reviewers for helpful suggestions on the earlier versions of the paper.

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All Supplementary materials are available at: https://doi.org/10.11646/palaeoentomology.8.5.5

Supplementary materials:

SUPPLEMENTARY FIGURE S1. Example of PCP merging of light images: pair of female Protorhyphidae (Insecta, Diptera) from the Late Jurassic of the Daya River, PIN3063/1514 and 1515. **A**, Part. **B**, Counterpart (mirrored). **C**, Composite. **D**, **E**, Close-ups of **A** and **B**. **F**, Close-up of **C**. Scale bars: 1 mm.

SUPPLEMENTARY FIGURE S2. Example of PCP merging of previously published light images: *Nanoraphidia lithographica* Jepson, Ansorge & Jarzembowski, 2011 (Insecta, Raphidioptera), Lower Cretaceous of Spain, light photos. **A**, **B**, Part and counterpart (mirrored) images from the publication (Jepson *et al*., 2011), reproduced with permission. **C**, Composite. Scale bars: 1 mm.

SUPPLEMENTARY FIGURE S3. Example of PCP merging of scanning electron micrographs: thorax and abdomen of a female Archescytinidae (Insecta, Hemiptera) from the Lower Permian of Chekarda, preserved in lateral orientation, PIN 1700/240, images obtained with a backscattered electron (BSE) detector. **A**, Part. **B**, Counterpart (mirrored). **C**, Composite. Scale bars: 2 mm.

SUPPLEMENTARY FIGURE S4. Fragmentation and PCP merging of a compression fossil. The ventral and the dorsal sides of the stylized two-dimensional "bug" are opaque (**A**–**E**) or semitransparent (**F**–**H**). **A**, **B**, The dorsal and the ventral (mirrored) sides prior to fossilization. **C**, **D**, **F**, **G**, Part and counterpart (mirrored) images of the fossil. **E**, **H**, Composites. For details, see text.