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Fossil Focus: The Preservation of Colour

by Holly E. Barden[*1]

Introduction:

Colour is important in modern ecosystems, but the colours of extinct organisms are very rarely preserved in the fossil record. Colouration is most commonly seen in fossilized brachiopod shells and arthropod carapaces; however, establishing that these colours are original and not artefacts of fossilization processes is difficult. Until recently, few studies have attempted to do so, but within the past few years the subject has become an active area of research, with significant developments. There have been several studies investigating the morphological and geochemical evidence of pigments in birds and dinosaurs, as well as work on the colouration of insects. Such analyses have paved the way for major leaps forward in our understanding of the behaviour and life histories of extinct animals.

Morphological evidence of fossil pigments:

One of the most important breakthroughs in the study of fossil colour came in 2008, with the discovery of microstructures that closely resemble melanosomes in fossilized feathers from the Early Cretaceous Crato Formation of Brazil. Melanosomes are organelles held in soft-tissue structures such as skin and feathers which contain the pigment melanin. Melanin is ubiquitous across the natural world today and is found in two forms: eumelanin, which bestows dark colours such as black and brown, and pheomelanin which gives more yellowish or orange colours. The different forms of melanin are contained in melanosomes with distinctive shapes (Fig. 1). Eumelanin occurs in sausage-shaped eumelanosomes, approximately 1 micrometre (µm; 1/1000 millimetre) long, whereas pheomelanin is found in spherical pheomelanosomes that have a diameter of approximately 0.7 µm.

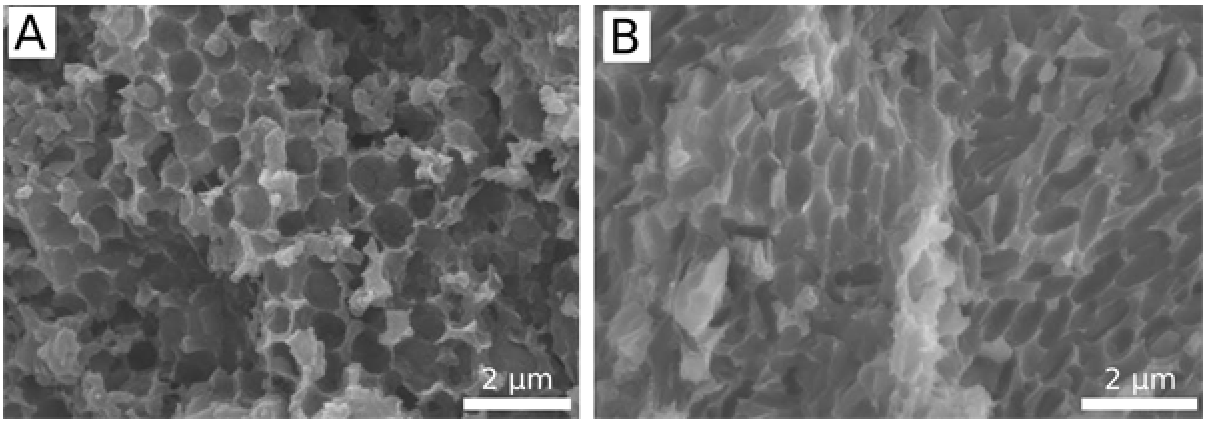

FIGURE 1 - FOSSILIZED CASTS OF PHEOMELANOSOMES (A) AND EUMELANOSOMES (B) FROM FILAMENTS ON THE DINOSAUR *SINORNITHOSAURUS*. IMAGES FROM ZHANG ET AL. (SEE FURTHER READING).

When these microstructures are preserved, researchers can note in which areas of the fossilized tissue different types are concentrated, and attempt a partial reconstruction of original colour. In a study of the feathered Jurassic dinosaur *Anchiornis huxleyi*, fossilized melanosomes were compared with melanosome structures in modern black, grey and brown feathers to determine which type they most closely resembled and build up a picture of the colour and patterning of the feathers as they might have appeared in life. This type of work has now been done on a variety of soft-tissue fossils of birds and dinosaurs, resulting in increasingly accurate portrayals of these animals (Fig. 2).

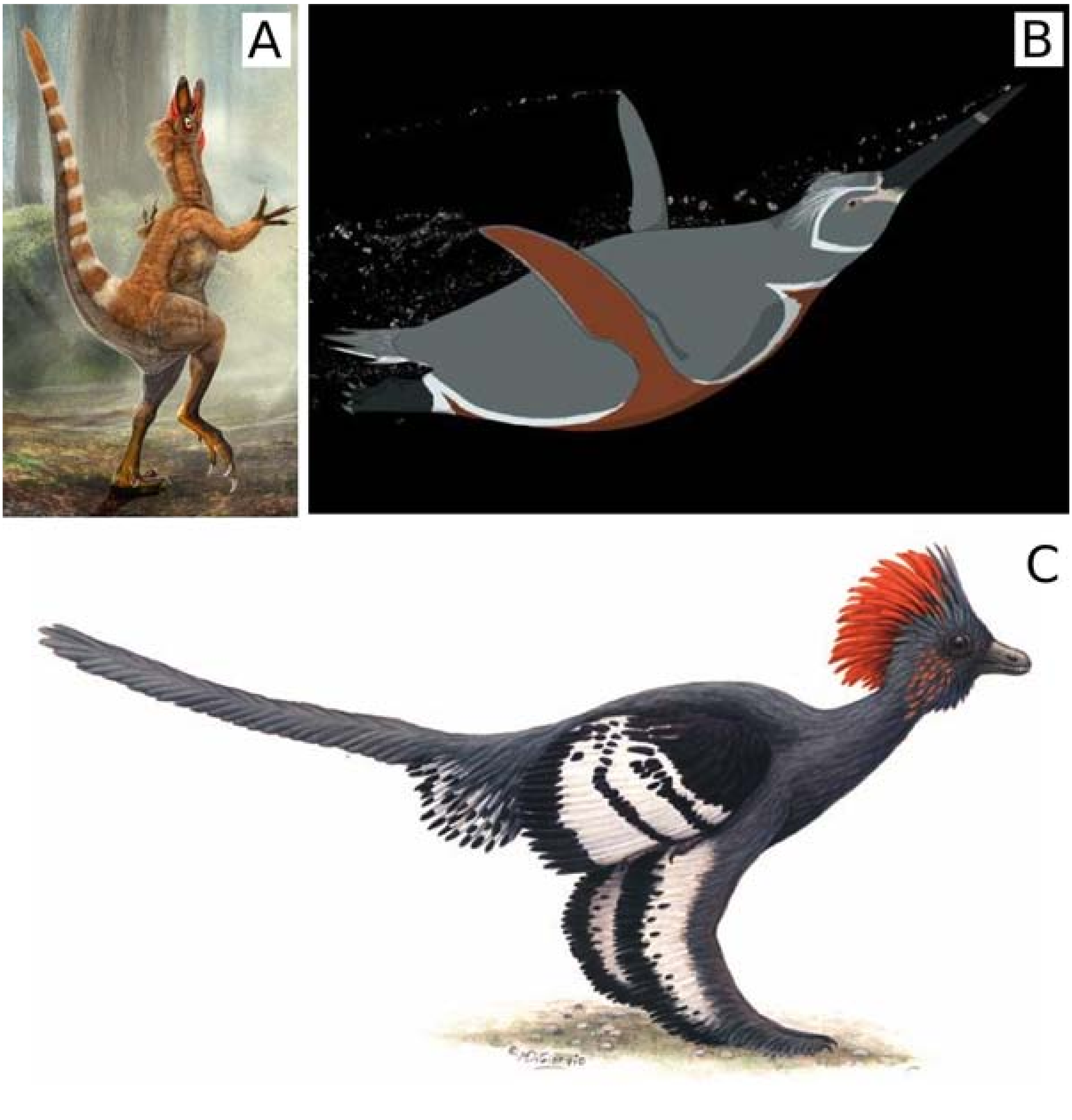

FIGURE 2 - PLUMAGE RECONSTRUCTIONS OF (A) THE DINOSAUR SINOSAUROPTERYX (BY CHUANG ZHAO AND LIDA XING; SEE ZHANG ET AL. IN FURTHER READING), (B) THE EXTINCT PENGUIN INKAYACU PARACASENSIS (BY KATIE BROWNE; SEE CLARKE ET AL. IN FURTHER READING) AND (C) THE JURASSIC TROODONTID ANCHIORNIS HUXLEYI (BY M. A. DIGIORGIO; SEE LI ET AL. IN FURTHER READING).

Geochemical evidence of fossil pigments:

Following the discovery and interpretation of fossil melanosomes, scientists started to analyse the geochemistry of fossil feathers. In collaboration with the Stanford Synchrotron Radiation Lightsource in California (see further reading, below), researchers have developed a method that allows them to image large fossil samples quickly and non-destructively to produce a two-dimensional map of the elements that they contain (Fig. 3). This technique is called synchrotron rapid-scanning X-ray fluorescence (SRS-XRF). A high-intensity X-ray beam excites the electrons in atoms at the surface of the sample, causing them to release energy in the form of light. Each chemical element emits a characteristic light energy, so by measuring the light that is released, researchers can confidently determine which elements are present in the sample. When SRS-XRF was applied to fossil feathers of the Early Cretaceous bird ***Confuciusornis sanctus***, researchers found concentrations of certain elements, especially copper (Fig. 3). Further analysis showed that this copper is organically bound — not part of an inorganic mineral, but actually from the animal itself. Copper is present in modern feathers and is a eumelanin 'chelate'; that is, it binds strongly to eumelanin. This may stabilize the copper, helping it to survive the rigours of preservation. Furthermore, in significant concentrations copper is toxic to most bacteria, and so may help to minimize degradation of the sample by microorganisms before fossilization. This data shows that copper can be used as a biomarker for the presence of eumelanin.

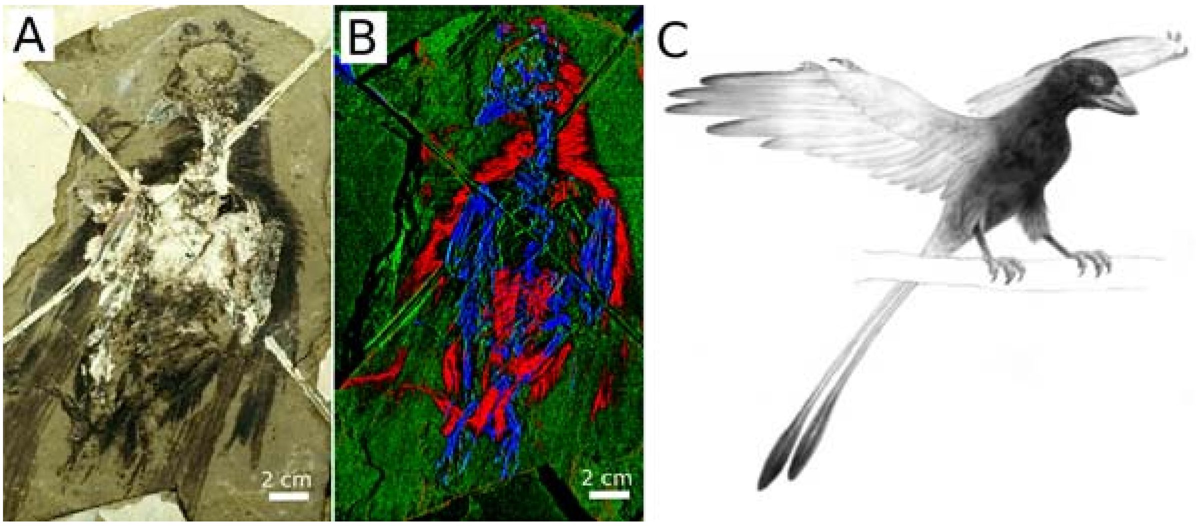

FIGURE 3 - VISUAL IMAGE (A) OF THE BIRD CONFUCIUSORNIS SANCTUS AND ITS ELEMENTAL MAP PRODUCED BY X-RAY FLUORESCENCE (B). COPPER IS SHOWN IN RED, CALCIUM IN BLUE AND ZINC IN GREEN. (C) BLACK AND WHITE ARTISTIC RECONSTRUCTION OF THE BIRD (BY RICHARD HARTLEY). IMAGES FROM WOGELIUS ET AL. (SEE FURTHER READING).

Evidence for the preservation of eumelanin has also been found using Fourier-transform infrared spectrometry. This enables the identification of functional groups: specific parts of molecules that determine how they react with other molecules. Infrared radiation is passed through or bounced off a sample, where it is absorbed by the bonds within molecules, causing them to vibrate at a characteristic 'resonant' frequency. Certain bonds absorb specific wavelengths of the radiation, providing a diagnostic absorption pattern that can be used to identify the bonds, functional groups and potentially molecules present in the sample. Fossil feathers analysed using this technique have showed the presence of functional groups characteristic of eumelanin. When mapped, these groups were found to occur only in the fossilized feather material and not in the surrounding stone (matrix) (Fig. 4). That suggests that the groups are products of the breakdown of the original feather pigment, and not the result of external chemical reactions with the matrix.

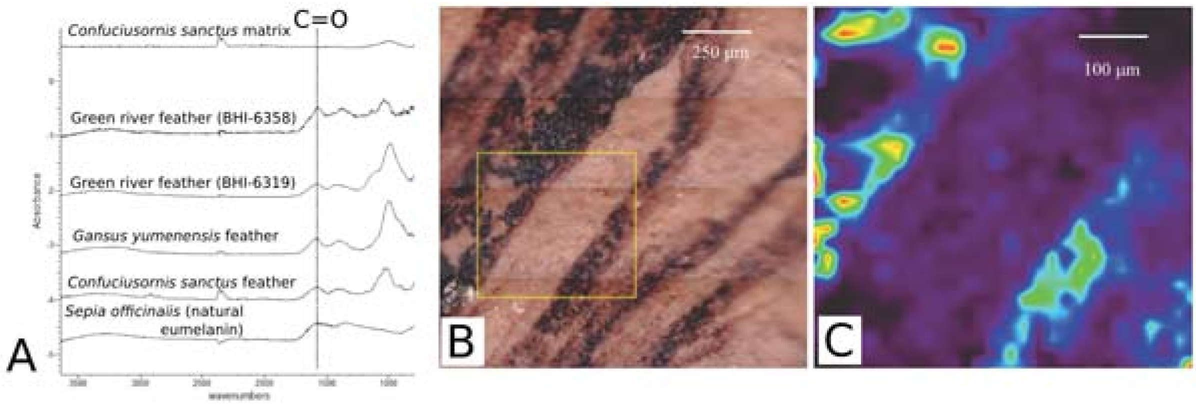

FIGURE 4 - (A) INFRARED SPECTRA TAKEN FROM FOSSIL FEATHERS, A MATRIX SAMPLE AND NATURAL EUMELANIN SHOW THAT THE FOSSIL FEATHERS CONTAIN THE SAME FUNCTIONAL GROUPS AS EUMELANIN. (B) VISUAL IMAGE OF SOME FEATHER BARBS FROM THE GREEN RIVER FORMATION (EOCENE, APPROXIMATELY 50 MILLION YEARS OLD) AND THE CORRESPONDING INFRARED IMAGE (C). (C) IS TAKEN FROM THE YELLOW BOX IN (B) AND SHOWS A MAP OF THE ABSORBANCE AT A WAVELENGTH OF 1,585 CM-1, REPRESENTING A C=O FUNCTIONAL GROUP CHARACTERISTIC OF EUMELANIN (SHOWN BY THE DASHED LINE IN A). NOTE THAT THE C=O GROUP OCCURS ONLY IN THE BARBS OF THE FEATHER. IMAGES FROM WOGELIUS ET AL. (SEE FURTHER READING).

Evidence of structural colour:

One of the problems with looking for evidence of colour in fossils is that in modern organisms, colour is the product not only of chemical pigments, but also of structural colouration — a phenomenon by which changes in the physical structure of a material alter the way light interacts with it, and hence how its colour is perceived. Therefore, to obtain a realistic picture of original fossil colour, we need evidence for both pigments in and structural components of the sample. Structural colour is responsible for most of the blue and green colours in modern bird feathers, as well as the property of iridescence: colour that seems to change depending on the angle at which the object is viewed. A study published in 2010 revealed evidence of iridescent colour in Eocene (50-million-year-old) feathers. It demonstrated that the eumelanosomes were arranged in a single solid layer over which there would have been a coat of the protein keratin, which has since decayed away (Fig. 5). This is the simplest physical structure that produces iridescence in modern birds.

Another study has attempted to reconstruct the structural colour in fossil moths and butterflies (lepidoptera) from the Messel oil shale of Germany (47 million years old). Lepidopteran wings are composed of layers of individual scales; different coloured scales display different internal structures, which interact with incoming light. The researchers reconstructed the original colour of these specimens by analysing the internal structure of the scales in the wings of the fossils. They examined the fine structure of the scale layering in cross-section using transmission electron microscopy (Fig. 5), and determined the wavelengths of light that the scales reflected (and therefore their preserved colour) using reflectance micro-spectrophotometry (MSP). They found that the colour determined by reflectance MSP differed from that determined from reconstructions based on microscope observations of the internal structure of scales. Studies on modern lepidopterans have confirmed that alteration of organic matter (as would occur during fossilization) changes the wavelengths of light reflected by the scales but does not affect their physical structure; therefore, the fine structure of fossilized scales can be used to accurately reconstruct their original colour using microscopy, even when it no longer reflects the same colours as it did in life (Fig. 5).

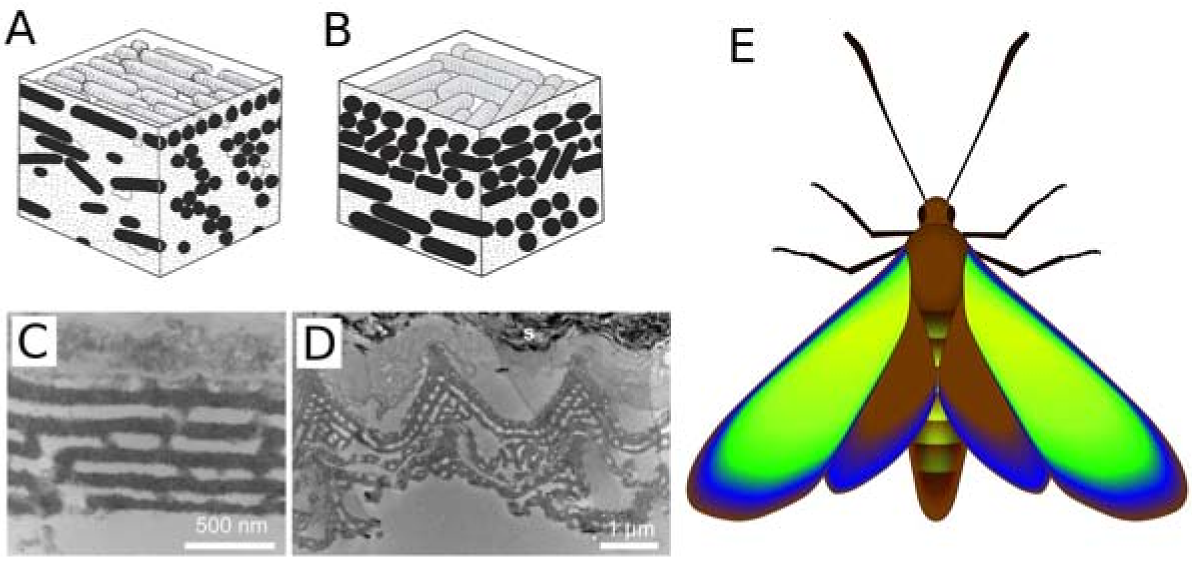

FIGURE 5 - (A) MELANOSOME STRUCTURE RECREATED FROM TRANSMISSION ELECTRON MICROSCOPY OF THE BLUE IRIDESCENT FEATHERS OF A MALE BOAT-TAILED GRACKLE (QUISCALUS MAJOR) AND (B) A MELANOSOME RECONSTRUCTION OF A FOSSIL FEATHER FROM THE MESSEL SHALE. IMAGES FROM VINTHER ET AL. (SEE FURTHER READING). LONGITUDINAL (C) AND TRANSVERSE (D) SECTIONS THROUGH FOSSIL LEPIDOPTERAN SCALES, AND THE SUBSEQUENT RECONSTRUCTION OF STRUCTURAL COLOUR (E). IMAGES FROM MCNAMARA ET AL. (SEE FURTHER READING).

Conclusions:

Improving our understanding of colour in fossil animals provides insight into the function of their external soft tissues (such as fur, feathers and skin). Debate still rages over the main function of such structures, and about why and how they arose in the first place. Establishing the colour and patterning of extinct organisms gives us an indication of whether they needed camouflage or warning signals, and potentially of whether their soft tissues evolved for a display function or for another reason, such as temperature regulation. There is, however, a lot more work to be done. As mentioned above, colour in living organisms is rarely the result of a single type of pigment or structural colour, but more usually derives from a combination of factors. Some studies have found evidence of chemical pigments called carotenoids in fossil brachiopod shells (see suggestions for further reading, below), but thus far this research has not been carried over to other animal groups. Further work is urgently needed to look for evidence of other such chemical pigments in fossils, not to mention the many other types of pigment that are now widespread in the natural world, and those that are now extinct. Nevertheless, the study of colour in fossils is becoming an increasingly active area of research and promises many more interesting findings.

Suggestions for further reading:

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