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Geology 4 Evolutionary Palaeontology course.

Essay: *Darwin worried about whether his theory of Natural Selection could account for the functional perfection of such an organ as an eye. Would he still worry about it in the light of modern knowledge?*

Introduction

In the mid-nineteenth century, Darwin had unveiled his theory of Natural Selection to the world setting in motion one of the most extraordinary scientific breakthroughs of all time. To say that he did not have some reservations about some of the more fantastic claims advanced by the theory is untrue. I hope to show that this was the case, and then to show by describing scientific models for the evolution of the eye and wing, why I believe Darwin would have little trouble in accepting his own far-reaching ideas.

Historical and Contemporary Setting and Concerns.

In ‘The Origin of Species’ (1859), one of Darwin’s reservations about the theory of Natural Selection is manifested on the subject of the origin of organs of extreme perfection and complication when he says (p. 217) “To suppose that the eye, with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest degree.”. He goes on to state briefly how a spectrum of levels of sophistication of eyes in contemporaneous genetically-close species might offer a reason to believe the theory in explaining evolution of such organs, before finishing cautiously with (p.219): “…reason ought to conquer…imagination, though I have felt the difficulty far too keenly to be surprised at any hesitation in extending the principle of natural selection to such startling lengths.” In these quotes we can see that Darwin was clearly troubled about whether his theory could explain the origin of such features. His contemporary critics expounded this worry as in Gould’s 1991 interpretation of his critics (p. 140): “We can readily understand how complex and fully developed structures work and how their maintenance and preservation may rely upon natural selection…But how do you get from nothing to such an elaborate something if evolution must proceed through a long sequence of intermediate stages…? You can't fly with 2 percent of a wing or gain much protection from an iota's similarity with a potentially concealing piece of vegetation.". Resolution of such matters is not only confined to an historical context, as creationists still cite the existence of such features in order to bolster refutal of evolutionary theory. For example Menton (1997) uses a computer's processing power and it's minuscule capacity in comparison with the processing capacity of the human retina as an analogy, concluding: "...if a supercomputer is obviously the product of intelligent design, how much more obviously is the eye a product of intelligent design?". Arguments such as these assume an inherent purpose to evolution, where evolutionists maintain that the operation of random small mutations at the genetic level drive the process. Other arguments, such as in Berlinski (1996) highlight unexplained intermediate stages in the evolution of organs such as the elephant's trunk as a means of rebuttal of the theory. Detailed scientific models exist which I think show quite clearly that Darwin would have little difficulty today in accepting his original propositions.

Evolution of Organs of Extreme Perfection.

Two Swedish scientists, Dan Nilsson and Susanne Pelger, published a paper in 1994 that set forth their results of computer modelling of evolution of a camera-type eye with lens such as is developed in vertebrates and octopuses. They set out to answer two important questions relevant to this argument:

1) Is there a smooth gradient of change, from flat photocell to full camera eye such that each intermediate stage represents an improvement in operation?

It is important to ascertain this because if evolution is to be shown to operate then it must occur by gradual change, with each incremental step delivering a short-term benefit, the size of the benefit controlled by the size of the evolutionary step.

2) How long would this amount of evolutionary change take?

This is also an important point because if it cannot be evaluated or takes an inordinately long time (longer than the age of the Earth, for example) then the model is of little value. Interestingly, within different invertebrate groups, it is believed that image-forming eyes have evolved from scratch between forty and sixty-five times from palaeontological studies (Dawkins, 1995; Lindsay, 1998). The model of Nilsson and Pelger used a flat eyespot as a starting point to avoid the extra complication of cellular evolution of the first photocell.

They only modelled tissue, which can change in different ways under the influence of random mutations. It can change such that sheets of it can become larger or smaller in area, thicker or thinner, and transparent tissue can undergo a local change in refractive index. This shows how the structure of an evolving eye might change, but how might the efficiency of a structure be measured? Using the laws of elementary optics, a computer can easily calculate the spatial resolution of a two-dimensional eye in cross-section. There are two ways in which spatial resolution can be introduced. The first is by forming a central depression in the light sensitive material, and the second is by constriction of the dark pigment layer. These two factors both operate to reduce the angle through which light is received – a focussing or increased resolution (Nilsson & Pelger, 1994). Nilsson and Pelger's model began with a flat retina over a flat pigment layer, both beneath a protective transparent layer. With these parameters built in to the model, it was allowed to run invoking localised random mutations in the transparent layer's refractive index, followed by random deformation over the whole model. The testing condition was that any change must be small and be an improvement on the previous structure.

Figure 1 shows a representative sequence of stages of evolution of a model eye from flat light sensitive patch to highly evolved complex eye. Stage 1 is the flat light-sensitive patch which has developed a shallow central depression by stage 2, with the protective layer having thickened to fill the space with a vitreous substance. This process continues until the retina is hemispherical like that of a planarian. Stages 4 and 5 represent continued retinal growth but with no change in radius of curvature. These stages mark a shift from deepening of the central depression to constriction of the aperture. By stage 5 the aperture has reached an optimum dimension, such that any further decrease in size will shut out light to the detriment of resolution. At this point the model eye represents a perfect pinhole camera much like the eye of a nautiloid. No further increase in resolution can now occur without introduction of a lens. This takes place by a local increase in refractive index in the vitreous material, utilising (in vertebrates and cephalopods) proteins that are similar or identical to proteins with other functions. This causes a decrease in the focal length and images become better resolved without loss of brightness. As this process continues, a graded-index lens is produced. This is a lens where there is a smooth gradient in increase in refractive index from edge to centre. This represents a superior type of optical design, which helps to limit the size of the optical apparatus and reduce visual aberrations, such as is seen in fish and cephalopods. Stage 6 represents the appearance of a graded-index ellipsoidal lens at a position distal to the retina, as this is the best position for the introduction of a lens in a pinhole-type eye (Nilsson & Pelger, 1994). It is known that the best optical results in this type of eye are achieved when certain optical conditions are satisfied. For example, many aquatic animals eyes have a spherical graded-index lens which is situated in the centre of curvature of the retina and gives a virtually aberration-free 180° field of view. A typical feature is that the focal length is 2.55 times the lens radius. This relation is called Mattiessen's ratio and represents an ideal solution for a lens with central portion of refractive index 1.52. In the model stages 6-8, a steadily increasing resolution occurs when the lens moves towards the centre of retinal curvature and simultaneously becomes more spherical, adjusting its size to conform to Mattiessen's ratio, forming an iris by stretching of the original aperture. Interestingly, eyes closely representing each part of the model can be found among contemporary species.

This certainly seems to answer the question of 'how?', but the model was also used to evaluate 'how long?'.

To do this Nilsson & Pelger calculated the number of 1% changes in the various parameters between stages in figure 1, so for example doubling the length of a structure takes 70 × 1% steps since $1.01^{70} \approx 2$. In this way all structures were analysed and the number of steps required is displayed in figure 1 between stages, totalling 1829 steps. This is equivalent to a structure becoming 1.01^{1829} or 80 129 540 times longer. They then applied this to an equation to evaluate the observable change, R, in each generation:

$$R=h^2iVm$$

which depends on the heritability, h^2, which is a measure of how far variation is governed by heredity, i is the intensity of selection, m is the mean and V measures the ratio between the standard deviation and the mean.

They deliberately chose low values for these parameters, hoping to use the results to go some way toward explaining the large number of separate eye evolutions in the fossil record. Using the equation, they calculated a change between each generation of 0.005% and then plugged this value back into the calculation of 1% changes in structure so that 1.00005^n= 80 129 540 where n is the number of generations involved in accruing 0.005% differences. This value is about 350 000 generations. So for something like a small to medium sized aquatic animal which compares to the model, a generation time of one year is suitable and this then means that an eye could evolve from flat patch to complex camera-type lens eye in about 350 000 years. Even with the conservative estimates employed in the model, from the time since the mid Cambrian there has been enough time for the eye to evolve fifteen hundred times in any one lineage.

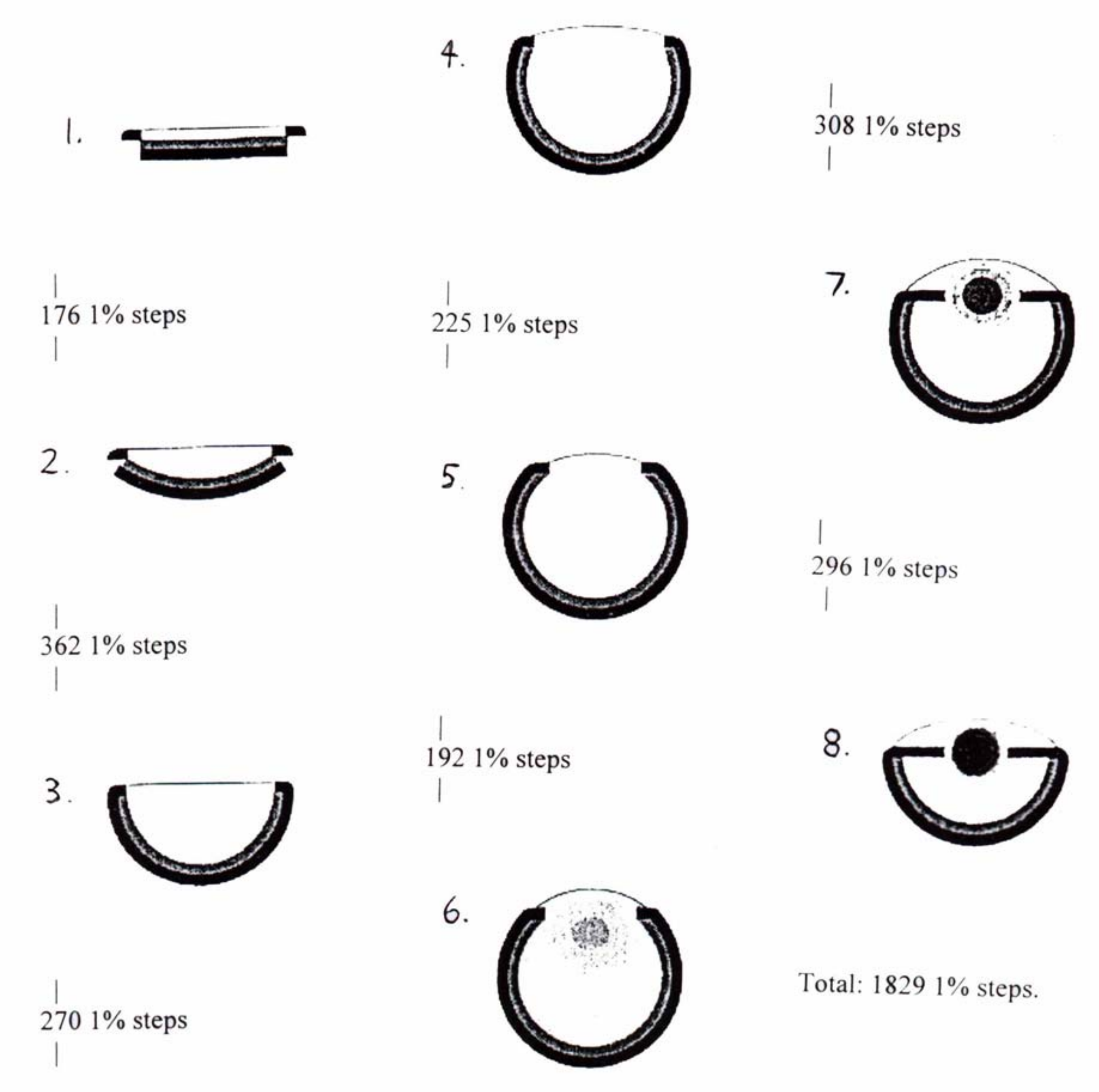

Figure 1. Computed model showing representative stages
in the evolution of a complex camera-type eye with lens.
See text for explanation. (Nilsson & Pelger, 1994)

Another oft-cited example of a functionally perfect organ, the wing, commonly causes consternation, but I hope to show its selection path can be rationally elucidated and lends support to my argument.

The difficulty in accepting how a wing might have evolved from no wing comes from having overlooked part of Darwin's theory called functional shift. This idea supposes that from the first appearance of a proto-organ to the state of perfection in question, an organ may have been used to perform one or more different functions over its evolutionary course (Gould, 1991).

Several conclusive experiments have been carried out to evaluate a postulated alternative origin for insect wings, which highlights an evolutionary pathway for their origin. In experiments by Kingsolver and Koehl (1985), they began by constructing mathematical equations related to aerodynamic properties. The next stage was to build replica bodies of flying and non-flying early insect fossils and attach wings of various sizes to them. Wind tunnel experiments yielded the aerodynamic data and led to some strong conclusions:

- For any body size and shape, aerodynamic benefits begin at a certain size of wing, and increase with increasing wing size.
- At the very small proto-wing size seen in many early fossils, the benefits are small or negligible and do not increase with increasing wing length.

It has long been known that insects also use wings for thermoregulation. Kingsolver and Koehl tested their models for thermoregulatory effects by constructing different sizes of wings from two materials with different thermal properties, construction paper and aluminium foil. The models temperature changes were measured against wingless bodies and these experiments again produced some strong conclusions:

- For thermoregulation, small wings work well, with benefits increasing with increasing wing size.
- Beyond a threshold size, increasing wing size imparts no additional effect.

The combined conclusions from these studies are shown as figure 2 and can be stated very concisely: for any body size, there is a wing length above which there are no additional thermal effects, and one for below which there is no significant aerodynamic effect (Gould, 1991). The important features of figure 2 are:

i) how thermal effects produced by small but growing wings increase rapidly to a point where the increasing wing size has no effect, and conversely

ii) how aerodynamic benefit has no effect at small wing size but occurs with intermediate size, and increases with larger wings thereafter. These results are amazing in the sense that the location where wing size is at the threshold between benefit and no gain between the two properties, represents the domain of functional shift between the two.

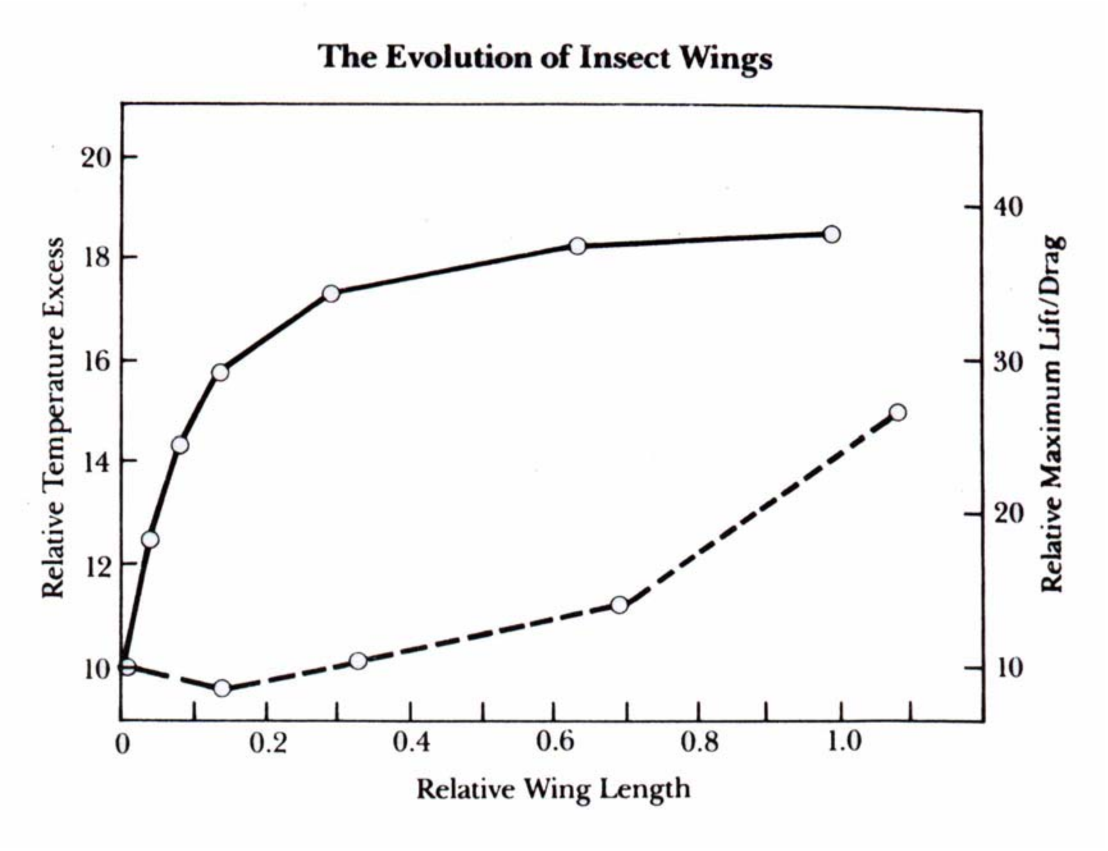

Figure 2. The thermoregulatory (upper curve) and aerodynamic (lower curve) advantages for increasing wing length in insects (Gould, 1991).

One question remains however, and that is what caused a shift from thermoregulation as function (presumably the initial function) to aerial effects as function? Kingsolver and Koehl found that this domain varied according to body size such that a larger body switches to aerodynamic function at a relatively smaller wind size. A possible scenario is that an insect with optimum wing size for thermoregulation would not have evolved larger wings for aerial use, but if other evolutionary pressures caused an increase in body size then the same ratio of body to wing size could be such that the threshold of aerodynamic benefits might be crossed as an accidental by-product of thermoregulatory function.

Conclusion.

Clearly Darwin was worried by the enormity of the task of using his theory to explain such amazing constructions as the eye or the wing, even though his tenuous proposals to achieve this were not too far from reality. These two examples of scientifically ascertained evolutionary scenarios for the realisation of complex organs go a long way toward explaining why I think Darwin would not be particularly worried today about how such things could come about. Even though many examples of organ intermediate stages remain unexplained, as many creationists are apt to point out as proof of the illegitimacy of evolution theory. Just because we don't yet understand the evolution of an organ (as was once the case with the eye and the wing) doesn't mean that its evolution did not occur.

References.

Berlinski, D. (1996), Keeping an Eye on Evolution. Webpage; http://www.rae.org/eyeevol.html

Darwin, C. (1859), The Origin of Species by Means of Natural Selection. pp. 477

Dawkins, R. (1995), River out of Eden. pp.

Gould, S.J. (1991) Not necessarily a wing, *in* Bully for Brontosaurus. pp. 540

Kingsolver, J.G. & Koehl, M.A.R. (1985), Aerodynamics, thermoregulation, and the evolution of insect wings: Differential scaling and evolutionary change. *Evolution* **39**, 488-504.

Lindsay, D. (1998), How Could an Eye Evolve? Webpage; http://www.cs.colorado.edu/~lindsay/creation/eye.html

Menton, D.N. (1997), Can Evolution Produce an Eye? Not a Chance! Webpage; http://gennet.org/Metro10.htm

Nilsson, D-E. & Pelger, S. (1994), A pessimistic estimate of the time required for an eye to evolve. *Proc. R. Soc. Lond* . B, **256**, 53-58.