and Mizar, generally with Mizar above. Two pyramids that do not conform to this pattern — the second great pyramid at Giza (Khafre) and the later pyramid of Sahure — can easily be explained if the north alignment was done with Kochab above Mizar, producing an error to the west instead of the east.

Spence argues that there was an elaborate 'fixing the north' ceremony that took place early in a new pharaoh's reign, rather than a systematic sequence of observations over months or years. It is an interesting idea, but one that needs to be tested. Can Egyptologists find references to such a ceremony in the ancient texts? This evidence would seem to be crucial for the ultimate acceptance of Spence's ingenious hypothesis, but sadly there is no documentation relating to the construction of the ancient pyramids.

In general, little is known about early Egyptian astronomy, and even the constellations recorded on the ceilings of tombs remain for the most part unknown and unmatched with the actual starry sky. One of the few identified constellations is the Egyptian adze, the sculptor's mythically powerful tool for making magical images; the adze matches the modern Big Dipper. A pair of such images are depicted in the wall mural of Tutankhamon's tomb — probably the Big and Little Dippers — and elsewhere there is a text about two sharp claws chasing each other around the pole. Could this be an echo of Kochab and Mizar making their alignment rounds? Be on the lookout, Egyptologists, for any such obscure hints. ■

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Speciation

Fish found *in flagrante delicto*

Mark Kirkpatrick

Genetic analysis of cichlid fish in Nicaraguan lakes reveals a possible case of repeated sympatric speciation: the creation of two species from one in the same environment.

A species of vertebrate gives rise to another species on average once every few million years. That is somewhat longer than the time span of a typical research grant, which is one reason why speciation is a tough subject to study. But sometimes the process can be caught in the act, giving us a window onto the origin of biodiversity.

A paper by Wilson *et al.*[1], just published in *Proceedings of the Royal Society*, reports on just such an apparent case in cichlid fishes from Nicaragua. The contribution is all the more interesting because it seems that sympatric speciation is taking place. This is the controversial hypothesis which holds that one species can split into two without the benefit of geographical barriers to prevent interbreeding.

The celebrated evolutionist Ernst Mayr built a persuasive case that speciation can occur only when geographical barriers enforce non-random mating while new species are emerging[2]. This is allopatric speciation, and Mayr's view became the orthodoxy for many years. There is now growing evidence, however, that sympatric speciation can happen in the right circumstances[3]. The study by Wilson *et al.* breaks new ground by providing the first example of replicated sympatric speciation: one species splitting in two several times independently. If confirmed, these natural replicates would offer a unique opportunity to identify the factors that trigger sympatric speciation.

The cichlid fishes are particularly attractive for speciation studies. The 700 species are remarkable for their diverse colours, shapes and sizes, and behaviours (which include complex courtship and parental care). Cichlids can speciate rapidly: the 300 species in Lake Victoria, east Africa, may have descended from a single ancestral cichlid in only the past 12,400 years[4]. Further, these fish may be prone to sympatric speciation. A remarkable case involves cichlids from isolated crater lakes in Cameroon[5]. Genetic data show that nine species living in Lake Bermin are each other's closest relatives, implying that they speciated there. The lake is only 0.6 km^2 in surface area and 14.5 m deep, making it implausible that geographical barriers were involved.

Wilson *et al.*[1] studied cichlids in four lakes in Nicaragua. Each lake has two types of fish that differ in colour — a 'normal' morph and a 'gold' morph. In two of the four lakes, Wilson *et al.* found statistically significant differences between the nuclear and/or mitochondrial gene frequencies of the morphs. Further, mitochondria from the different morphs within each lake are statistically more similar to each other than to those from different lakes, supporting the authors' interpretation that sympatric speci-

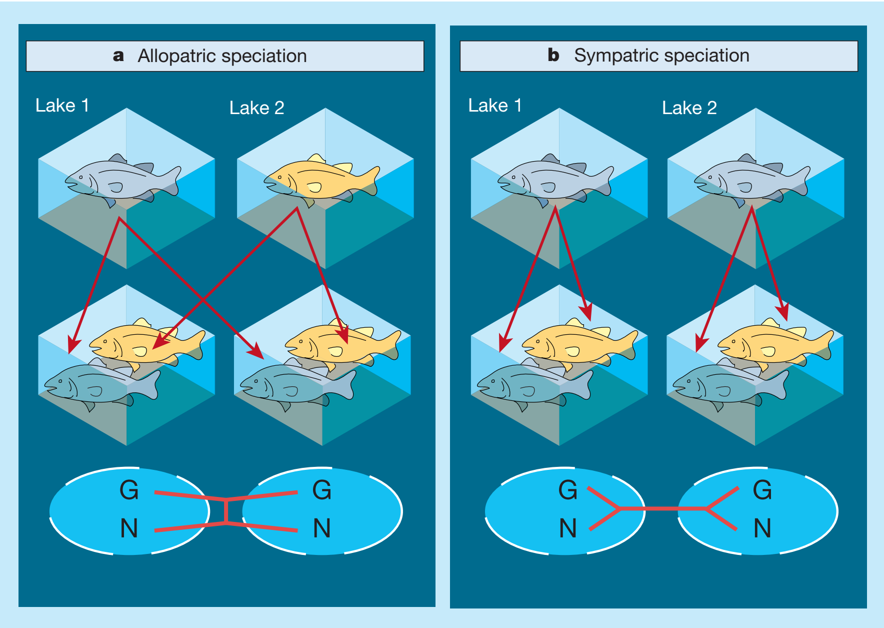

Figure 1 **Molecular signatures of speciation: possible outcomes of genetic analyses of cichlid fish in two Nicaraguan lakes.** a, **Allopatric speciation, in which species form while a geographical barrier is present and then come into contact secondarily.** b, **The corresponding pictures for 'replicated sympatric speciation', where new species form independently within each lake in the absence of geographical barriers. At the bottom is the gene tree for genes from gold (G) and normal (N) individuals sampled from the two lakes that would be consistent with each course of events. The gene trees reflect the historical relations of the populations. Under allopatric speciation** (a), **genes from the gold forms in different lakes will be more similar than genes from the gold and normal forms within each lake. The opposite is true under sympatric speciation** (b).**Wilson and colleagues' data[1] tend to support this second pattern, and the view that sympatric speciation has occurred.**

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ation has occurred (Fig. 1). Other explanations are that allopatric speciation occurred on a local scale within each lake; or that parallel invasions of the lakes by two species that originated in different lakes were followed by hybridization between the two, and the spread of mitochondria from one species to the other. These alternatives may be less likely, but they serve to show how hard it is to prove sympatric speciation conclusively, even with solid molecular data.

Earlier studies of these fish[6] found strong 'assortative' mating based on colour (that is, like-colour morphs mate with like). Population-genetic models show that assortative mating is a particularly powerful mechanism for generating the genetic differences that lead to speciation[7], so this propensity may have set the stage for sympatric speciation. Even one successful hybridization per generation should prevent substantial divergence for the molecular markers studied by Wilson *et al.*[8], so apparently there have been strong barriers to genetic mixing between the colour morphs for quite some time.

There is another striking form of variation found in these fish. Cichlids have distinctive bones in their throats called pharyngeal jaws, which have played a key role in their spectacular ecological diversification[9]. The Nicaraguan cichlids have two forms of these jaws, one suited to a diet of snails and the other to soft prey. Typically, speciation involves genetic divergence for ecological traits, and so one would expect one of the two forms of pharyngeal jaws to be strongly associated with each of the colour morphs. They are not. Although there is a correlation, it is only weak (about $r = 0.48$). Further, Wilson *et al.* could not find molecular differences between the pharyngeal morphs.

What gives? Two possibilities come to mind. The first one, favoured by the authors, relates to mathematical models of sympatric speciation[10,11]. Consider a population that is under divergent selection for two different ecological forms, say eating snails and eating worms, and that also mates assortatively, say with respect to colour. The models show that genetic variation for the ecological trait and for colour will become correlated. This correlation further reinforces divergence of both the ecological trait and colour, and under the right conditions it can cause the population to split in two completely within only a few dozen generations. The Nicaraguan cichlids could be at an intermediate step in this process, in which case the colours, pharyngeal jaws and molecular variation will eventually become tightly associated. A difficulty with that suggestion, however, is that the molecular data suggest the colour morphs have already been isolated for a considerable time.

There is another possibility: that the dramatic variation in pharyngeal jaws may not have genetic causes. The pharyngeal jaws of these fish change their form in response to diet[12]. The two colour morphs live in different habitats at certain times of the year, where different prey are available. Perhaps diet alone directly causes the variation in pharyngeal jaws and its modest correlation with colour. In that case, the jaws may be but an interesting sideshow to speciation.

Non-genetic effects might have a hand in yet another part of this story. In these cichlids, the young spend several weeks in the care of both parents, giving offspring the opportunity to learn the colour of their parents. Perhaps the mating preferences of the fish are influenced in part by behavioural imprinting. Indeed, lab experiments on these cichlids suggest that a fish's response to gold and normal individuals is not affected by its own colour, but is affected by the colour of the parents that reared it[13]. Imprinting may influence speciation in birds[14], so there might be a connection between two remarkable features of cichlids — their high rates of speciation and their parental care. ■

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Nanothermodynamics

Breathing life into an old model

Tom Giebultowicz

A classic theory of magnetism has been modernized by a novel use of thermodynamics. The theory can now describe the behaviour of ferromagnetic materials at higher temperatures.

The mean-field theory of ferromagnetism, put forward in 1907 by Pierre Weiss[1], was an important milestone in the development of modern physics. For many years, the Weiss theory was the 'Standard Model' of magnetism. Apart from describing the magnetic properties of materials such as iron, it stimulated great interest in the study of interacting systems, which had an impact far beyond magnetic research.

The theory is still widely used today, even though its predictions are not accurate at certain temperatures. Because of its popularity, attempts to improve the theory's predictions are still worthwhile. One such refinement is reported on page 337 of this issue by Ralph Chamberlin[2]. By including the effects of small-system thermodynamics (nanothermodynamics) to describe local magnetic fluctuations, Chamberlin has extended the mean-field approach to cover the behaviour of ferromagnets at higher temperatures.

The problem tackled by Chamberlin has a long history. Work towards quantitative models of magnetism began in the late 1800s, shortly after classical electromagnetic theory was formulated by J. C. Maxwell. The first successes were in studies of paramagnets and diamagnets — materials that are weakly magnetic under an applied magnetic field (and the magnetization is aligned with the applied field or opposing it, respectively). In 1895, Pierre Curie derived a magnetization law for paramagnets from experiments. Paul Langévin, Curie's pupil, later showed that the law could be derived theoretically by treating a paramagnet as a system of classical non-interacting magnetic dipoles. He also managed to explain diamagnetism using classical electromagnetic theory. But this theory completely failed in its attack on ferromagnets — the materials in which magnetism is strongest. In ferromagnets a sizable magnetization can remain in the material even when there is no external field.

Ferromagnetism abruptly disappears from a material at a certain critical temperature called the Curie point, T_C. Above this, the system behaves as a paramagnet until it is cooled back below T_C and ferromagnetism is restored. Classical physics can explain such effects only if T_C values are at least 1,000 times lower than those observed. Pierre Weiss solved this puzzle by postulating the existence of anomalously strong interactions between the atomic magnetic dipoles. He introduced the interactions into his calculations as a homogenized 'molecular field' proportional to the magnetization. The new model was a spectacular success, qualitatively describing observations at all temperatures.

In particular, for temperatures above T_C, Weiss's model provides an equation for the magnetic susceptibility χ, so that $\chi(T) \propto C/(T - \Theta)$, where C is the Curie

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