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Lizards took express train to Polynesia

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Lizards took express train to Polynesia

The pattern of human colonization of the islands of the central and eastern Pacific is contentious. Two models have been widely considered: the 'express train to Polynesia' and the 'entangled bank' hypotheses¹⁻⁴. Here I analyse the mitochondrial DNA sequences of the lizard *Lipinia noctua*, which lives alongside humans on these Pacific islands, with a view to distinguishing between these two hypotheses. From a phylogenetic analysis of mitochondrial DNA sequence variation, I find that these lizards colonized the central and eastern Pacific as a result of human-mediated dispersal, presumably as stowaways on early Polynesian canoes. The extreme genetic similarity between the different colonies indicates rapid colonization from a single source, which I take as support of the express-train hypothesis.

The Pacific Ocean is the world's largest geographic feature, encompassing more area than all the continents combined, and the islands of the eastern Pacific were the last part of the world to be colonized by humans. The voyage to these islands has attracted attention because it could provide clues as to how human cultures evolved. The entangled-bank hypothesis² argues that movement into the central and eastern Pacific was a gradual event, occurring over an extended period from different Melanesian populations. In contrast, the express-train hypothesis¹ argues for rapid colonization from southeast Asia, with colonists moving through Melanesia and into the Pacific with little genetic exchange occurring between different groups.

Archaeological⁵, linguistic⁶ and genetic⁷⁻⁹ data indicate that human migration from the Taiwan region to the Bismarck archipelago, northeast of New Guinea, occurred between 3500 BC and 1600 BC. The Lapita expansion, from the Bismarck islands into the central Pacific, is thought to have happened over a short period, perhaps only a few hundred years^{1,3,5}. The further extension of humans into the eastern Pacific was slower, and the most remote regions were not reached until much later⁴ (Fig. 1).

Lipinia noctua, a small lizard native to New Guinea, is a single species with one of the broadest distributions of any lizard. It occurs from the Papuan region throughout Oceania, to the Hawaiian islands in the northeast, and Easter Island and Pitcairn Island in the southeast. Because of the large ocean barriers and the morphological similarity between island populations, dispersal of the lizard from New Guinea was presumed to have been mediated by humans.

To investigate any potential congruent phylogeographic patterns between humans and this lizard, I collected mitochondrial

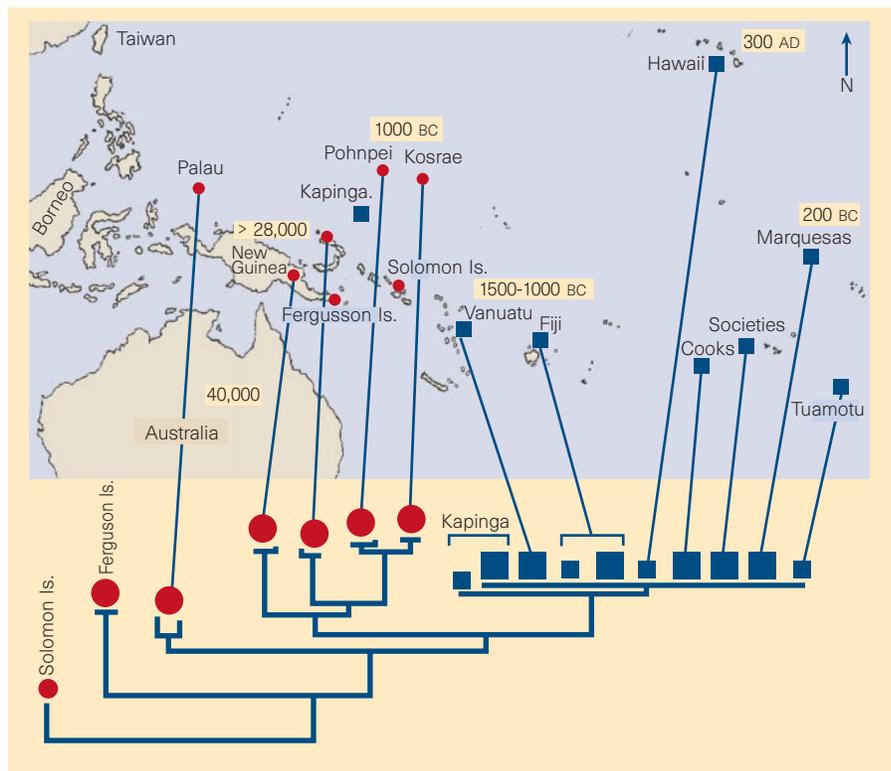


Figure 1 Maximum-parsimony phylogram for *Lipinia noctua*. Maximum-likelihood analyses produced the same topology. Symbol size represents sample size (small, $n=1$; large, $n=2$). Localities denoted by blue circles are all genetically distinct from one another (mean sequence divergence, 9.7%) and represent natural pre-human dispersal¹⁰. Localities denoted by red squares are genetically similar (mean sequence divergence, 0.008%) and represent human-mediated dispersal within the past 4,000 years. Kapinga indicates Kapingamarangi atoll. Dates represent approximate time of first human settlement⁴. (R. Fisher, J. Lum and D. Mindell, personal communication.)

DNA samples from 29 *L. noctua* lizards from 15 island populations (Fig. 1). From these samples, I sequenced and aligned a 300-base-pair portion of the gene encoding cytochrome *b* and analysed the results by maximum-parsimony and maximum-likelihood phylogenetic reconstruction methods using appropriate outgroups (Fig. 1).

The entangled-bank hypothesis predicts that *L. noctua* populations in the central and eastern Pacific should be paraphyletic (red and blue populations intermixed in Fig. 1) as a result of several dispersal events that reflect the different human migrations from Melanesia. The express-train hypothesis, however, predicts that *L. noctua* in the central and eastern Pacific should be monophyletic (red populations grouped together in Fig. 1) and show a high degree of genetic similarity because of a bottleneck associated with rapid human-mediated dispersal.

The colonization pattern for *L. noctua* matches the predictions of the express-train hypothesis (Fig. 1). All central and eastern Pacific populations of *L. noctua* form a monophyletic clade that differ by no more than two base-pair substitutions. As

humans moved rapidly into the central Pacific, they could have inadvertently carried with them in their canoes a few lizards (or perhaps a single gravid female), causing the observed founder effect.

Although they are geographically part of Micronesia, the people of Kapingamarangi atoll are Polynesian in origin^{4,6}. The *L. noctua* from there are also of the central/eastern clade, which strengthens the association between *L. noctua* and human colonization. The lizard populations from the central and eastern Pacific should be equally closely related to an original source population, presumably somewhere in the Bismarck or Solomon archipelagoes. However, this source population, identifiable by greater haplotype diversity, has not yet been sampled. When it is identified, it may reveal archaeological information about the early stages of the express train's journey. The populations of *L. noctua* in Micronesia show a large degree of genetic divergence, indicating that they are the result of pre-human natural dispersal¹⁰.

The application of comparative phylogeography to evolutionary history, together

with information about population structure from other such 'vagabond' fauna and flora, should continue to shed light on the vagaries of human evolution.

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The first true inorganic fullerenes?

Boron nitride and materials of composition MX_2 , where M is molybdenum or tungsten and X is sulphur or selenium, can form fullerene-like structures such as nested polyhedra or nanotubes^{1–3}. However, the analogy to the carbon fullerene family⁴ falls short because no small preferred structure akin to C_{60} (ref. 5) has been found. We have discovered nano-octahedra of MoS_2 of discrete sizes in soots that we prepared by laser ablation of pressed MoS_2 targets. These nano-octahedra are much larger than C_{60} structures, having edge lengths of about 4.0 and 5.0 nanometres, and may represent the first 'inorganic fullerenes'.

Targets were prepared by pressing 98% pure MoS_2 powder and ablated using a KrF pulsed excimer laser (8 Hz, 248 nm, ~300 mJ per pulse, ~20 ns per pulse, ~10 J cm⁻²) under flowing helium or argon (500–800 torr, ~90 cm³ min⁻¹). The beam was moved every 4 minutes during the 20-minute runs to strike fresh target material, with the chamber and target temperature ranging from 30 to 600 °C. The soot generated was collected, ultrasonicated in acetone, and applied to a grid for imaging by transmission electron microscopy (TEM).

Soot produced between 30 and 500 °C contained crystalline and amorphous MoS_2 fractions, as well as smaller rhomboidal, rectangular and hexagonal structures 3 to 5 nm long with two or three layers. The crystalline material included large sheets and tubes and a variety of nested polyhedra 15

to 35 nm long that were similar to those produced previously⁶. Above 550 °C, only crystalline folded sheets of MoS_2 were produced.

TEM stage-tilting experiments on 30 two- and three-layered structures showed that the small rhomboids, rectangles and hexagons were different projections of the same three-dimensional structure: an octahedron (Fig. 1a). The TEM image for a closed three-layer structure changes with tilts of 10° and 20° (Fig. 1b). The image at 0° is the projection expected for an octahedron orientated such that only two triangular faces are seen. When it is tilted, the projection changes, resulting in a nearly rectangular projection at 20°. Stick models depicting how an octahedron's projection changes with tilting are also shown in Fig. 1b. The model octahedron was orientated to project a match to the 0° image, and the model was then tilted with the same axis used in the TEM. Many other TEM tilt

sequences could also be generated with projections of a model octahedron. In some cases, slight movements of the particles on the TEM grid ruined the correlation, but individual images could still be represented by the projection of an octahedron.

The edge length of the octahedron may be calculated from TEM projections, assuming a regular octahedral structure. A histogram of edge lengths for 30 different structures is shown in Fig. 1c. Two pronounced peaks are seen at 12–13 and 16 times the *a* lattice constant (the Mo–Mo distance, 3.16 Å) of MoS_2 for two- and three-layer species, respectively. The spacing between the layers is about 0.6 nm, in good agreement with the interlayer spacing in bulk MoS_2 . The edge of the three-layer species is about four *a* lattice constants larger than that of the underlying two-layer structure, exactly the size required to maintain the bulk interlayer spacing.

Although the reasons for these specific sizes are not clear, a preference for two- and three-layer structures may be associated with the two- and three-layer polytypes⁷. The octahedral shape might be anticipated for a closed MoS_2 structure as the triangular faces share the symmetry of the trigonal Mo and S sublattices. Rounded corners and edges are also expected for MoS_2 sheets, which cannot be severely bent without strain. Energy-dispersive spectroscopy indicated a Mo:S ratio of about 1:2 with no detectable impurities. Satisfying such a ratio exactly is impossible in an octahedron, but several arrangements come close. For example, the Mo–S coordination could remain trigonal prismatic, as in the bulk form, with a given face being slightly rich or poor in sulphur. The structure at the vertices is unclear, but either a four-membered Mo ring³ or a single Mo atom might be stable (B. Parkinson, personal communication).

TEM measurements could be performed only on nano-octahedra that were separated from the agglomerates formed on the TEM grid. Consequently, we cannot yet estimate the density of nano-octahedra in the laser-generated soots. We are purifying these inorganic fullerenes so that we can ascertain their properties, and are also finding out whether similar cage structures can be made using other layered materials.

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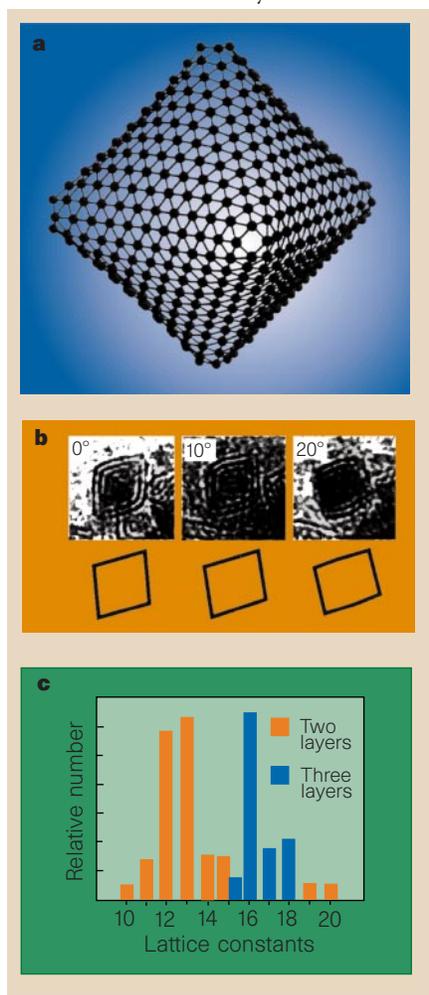


Figure 1 Structure of the molecules. **a**, Model octahedron with an edge length of 12 *a* lattice constants showing only the molybdenum sublattice. **b**, Transmission electron microscope images and model-generated projections for a three-layer MoS_2 rhomboid at 0° and undergoing tilts of 10° and 20°. **c**, Histogram of octahedral edge lengths in *a* lattice constants determined from 30 rhomboidal, rectangular and hexagonal projections observed by TEM.

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