country, is now among the world's ten richest despite its modest resources, while resource-rich Zambia is still poor. But Zambia acquired colonial state government barely a century ago, whereas Iceland has been a literate state for 1,100 years.

Besides those historical legacies, geography may also contribute to wealth through its effects on public health, agricultural productivity and transport costs[3,4]. The first two of those factors penalize tropical countries, and the last penalizes land-locked countries.

As regards public health, tropical countries tend to carry much heavier disease burdens than do those of temperate zones, because parasites and disease vectors thrive all year round in the tropics but not in temperate climates. Disease is obviously bad for economies: workers who have spent years training have lower productivity and fewer years to contribute to the labour force than they otherwise would; high child mortality drives parents to bear many children in the hope that some will survive, so that frequent pregnancy or lactation makes women less able to join the work force; and health costs drain government budgets.

As for agricultural productivity, one might at first expect higher crop yields in year-round tropical climates than in temperate zones. But the reverse is true, for reasons that include parasites and crop pests.

Finally, transport costs by boat are lower than those over land — and hence lower for countries with a sea coast, or with big navigable rivers, than for land-locked countries without such rivers. That helps to keep countries such as Afghanistan, Bolivia, Chad, Laos, Mali and Zambia poor.

The burdens on health and agriculture explain why tropical countries are on average poorer than those of temperate regions, and why until recently the more tropical parts of the United States and Brazil were poorer than their temperate parts. Proof of the pudding comes from Southeast Asia's 'tiger' economies, which have achieved spectacular growth in the past half-century. Hong Kong, Malaysia, Mauritius (in the Indian Ocean), Singapore, Taiwan and Thailand became rich precisely by recognizing their tropical penalties, and by investing heavily in overcoming them through public-health measures, family planning, and developing economic sectors other than agriculture (Fig. 1).

Moving beyond geography, there are at least three non-geographic explanations for differing national wealth: the paradoxical curse of natural resources, reversals of fortune after colonization, and environmental damage. Taking first the resource curse, a common-sense prediction is for countries rich in natural resources, such as minerals, oil and tropical hardwoods, to be wealthier than countries not so endowed. In fact, countries deriving much of their income or foreign exchange from natural resources — such as the Congo and Nigeria — are paradoxically poor[5–7]. Among the suggested reasons for this are that dependence on natural resources promotes civil wars (with people of resource-rich provinces seceding to control their local resources); it creates temptations for corruption; and it raises prices and wages, thereby stunting the growth of manufacturing and other economic sectors.

Acemoglu *et al.*[8,9] used the term "reversal of fortune" to explain differing economic changes among non-European countries colonized by European states in the past 500 years. The areas whose pre-colonial native societies had been richest (for example, Bolivia and Peru as parts of the Inca Empire, Mexico as the centre of the Aztec Empire, and India) are now poorer than pre-colonially poor areas such as Australia, Canada, New Zealand and the United States. Acemoglu *et al.* note, by way of interpretation, that areas that were formerly rich and densely populated but afflicted with tropical diseases were settled by few European colonists, who siphoned wealth from local people by exploitative institutions that today are bad for their economies as independent countries. In contrast, poorer areas where Europeans did not suffer high disease mortality did attract European settlers, who introduced institutions like those in their mother countries and more conducive to development.

Finally, a moment's reflection will suggest an objection to the idea that early agricultural origins lead to wealth[1,2]. By that argument, the world's richest countries should now be those where agriculture arose earliest: Iraq, Iran and Syria. In fact, all three are poor today, and would be even poorer were it not for oil. What happened? Their inhabitants had the misfortune to be living in fragile environments with low rainfall or high subsurface salt, which over millennia became damaged by deforestation, overgrazing, soil erosion and salinization. Those countries, too, experienced a reversal of fortune, but one due to environmental deterioration rather than colonial history[16]. Hence, a message from the studies described here is that aid donors should invest not only in institutions but also in public health, family planning and environmental protection. ■

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Nanophysics

A step up to self-assembly

Kristen Fichthorn and Matthias Scheffler

Powerful computer simulations have resolved the mechanism for the nanoscale assembly of the 'hut'-like clusters that form after a few layers of atoms have been deposited on certain solid surfaces.

From the beautiful snowflakes that form from a random aggregation of water molecules, to the creation of a living organism, nature has found such efficient means of self-assembly that, in contrast, human techniques often seem crude. Even in our most impressive technologies for fabricating microstructures on surfaces — such as the lithographic techniques used to create integrated circuits — human efforts still seem like chiselling patterns out of stone. At the nanometre scale, the resolution that can be achieved using lithography is reaching its limit, and a new set of tools is needed. By better understanding nature's methods for assembly on solid surfaces, involving diffusion, nucleation and growth, it might be possible to orchestrate these phenomena such that a complete computer chip consisting of several billion transistors could assemble itself, like a complex biological organism. Indeed, for nanotechnology to become affordable, nanostructures will have to build themselves; normal manufacturing methods will be useless. The laws of physics do not preclude this possibility, but our present understanding of surface physics is still too shallow to achieve such complex self-organization and assembly.

Zhu and colleagues[1], writing in *Physical Review Letters*, have quantified one of nature's mechanisms for creating nanometre-scale objects when atoms are deposited and grow into thin films on a solid surface of the same material (called thin-film homoepitaxy). Using computer simulations and a first-principles approach[2], these authors model how atoms 'rain' down on to a solid surface and diffuse across it, by hopping between surface binding sites. The atoms may aggregate to form nuclei, which then grow into islands. Whether an island retains a two- or three-dimensional shape depends, in the conventional perspective, on how easily atoms can 'step down' from the top of the island to the lowest unfilled layer of the developing film.

The first atomic-level insight into this process came in 1966 from the elegant field-ion-microscopy studies led by Ehrlich[3] and concurrent studies led by Schwoebel[4]. Ehrlich observed individual tungsten atoms hopping between binding sites on a tungsten surface and noted that when atoms approached downward step edges, they were often reflected away. This apparent repulsion was explained with bond-counting arguments: on flat crystallographic terraces, atoms have more bonds to other substrate atoms than they do if they are near the top of a step edge; there, the loss of substrate-atom bonds makes them less secure and hence they can be reflected from the edge. The energetic 'unwillingness' of atoms to descend step edges is now quantified by the Ehrlich–Schwoebel barrier.

On the basis of the same bond-counting arguments, homoepitaxial atoms residing at the bottom of a step edge of a close-packed surface should be the most secure, because they have a full complement of neighbouring atoms in the substrate below them and additional neighbours in the step edge beside them. It seems unlikely that these highly secure atoms would move upwards onto the tops of islands. However, evidence has been uncovered[5] for such upward motion in experimental studies of aluminium homoepitaxy on its less close-packed (110) surface, using atomic force microscopy and low-energy electron diffraction. After about ten layers of atoms had been deposited, at a temperature of about 400 K, nanocrystalline 'huts' were seen to emerge rapidly from the substrate, growing to a height of about 50 nm (equivalent to more than 200 atomic layers) after the deposition of only another 20 layers (Fig. 1a). The emergence of these structures indicates significant upward motion of atoms.

To investigate this unusual occurrence, Zhu *et al.*[1] used density-functional theory, which allows the quantification, with the best accuracy available, of the many-electron nature of chemical bonding at surfaces and how it dictates energy barriers, mechanisms and timescales for atomic motion. They show that on the (110) surfaces of a variety of metals (including aluminium), atoms ascend steps by incorporating themselves into the step edge and pushing a step-edge atom onto the top of the step (Fig. 1b). Interestingly, the energy barriers for this upward motion can be lower than barriers for downward motion.

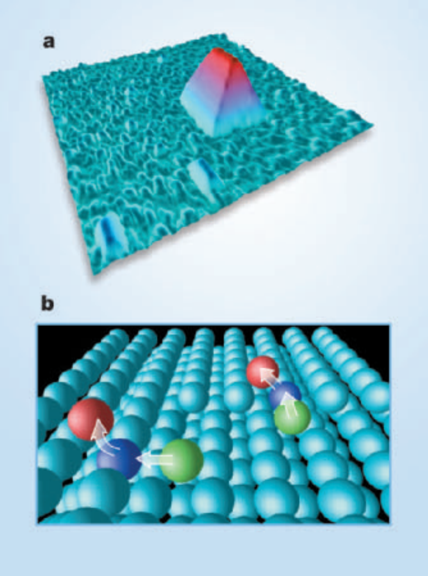

Figure 1 **Step-climbing and hut-building. a, A nanocrystalline 'hut', formed by a cluster of aluminium atoms on an aluminium (110) surface[2]. A total of 30 atomic layers have been deposited. The area of this atomic-force microscope image is 0.82 × 0.82 μm^2. b, Zhu *et al.*[1] suggest that hut-building is initiated by the upward diffusion of atoms at step edges on the (110) surface, even though this had previously been considered energetically unfavourable. An atom (green) at a step edge pushes an atom (blue) in the edge of the step onto the top (red), taking its place in the step.**

If atoms prefer to move upwards, why do they wait until ten layers have been deposited before beginning to form these monumental structures? To understand the relationships between the atomic processes that lead to assembly, Zhu *et al.* incorporated their results using density-functional theory into a simulation of the statistical mechanics of the system, called an '*ab initio* kinetic Monte Carlo' simulation[2,6,7]. The process of thin-film growth is simulated as a series of discrete events by choosing and actuating various atomic-scale processes (such as atomic deposition, atom hopping on a terrace, down a step, up a step, and so on) with probabilities based on their timescales.

Their simulations verify experimental observations: a few rough layers act as necessary precursors from which nanocrystals arise. The islands develop into small mounds whose sides form 'minifacets', or small surfaces with a different crystallographic structure from that of the (110) substrate. In this case, atoms race up the sides of the minifacets even faster than they step up single steps (such as those shown in Fig. 1b) and actuate the rapid rise of the huts.

Zhu *et al.*[1] have unravelled one of nature's secrets for self-assembly. But there is still a long way to go to achieve true mastery of the art, such that magnetic memory devices, catalysts or integrated circuits can be fabricated simply by throwing atoms onto a surface and letting them organize themselves. ■

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Molecular medicine

The writing is on the vessel wall

Christopher H. Contag and Michael H. Bachmann

Using an integrated approach, it is possible to identify the molecular addresses on blood-vessel walls that are read by blood cells — and, at least in rats, to deliver imaging agents and drugs to specific tissues.

Watching blood cells move through the blood vessels of living tissues under the microscope, researchers have learned that most of the time the cells move rapidly with the blood flow without stopping. Sometimes, however, they contact the walls of the vessel, slow down and roll along — perhaps even stopping and sticking in specific areas[1–4]. This and other indirect evidence has suggested that the endothelial cells that line the blood-vessel wall display different proteins on their surfaces according to where they are in the body and what events are occurring in a given organ. These proteins constitute the writing on the vessel walls — molecular 'addresses' that could tell circulating blood cells where they are and what to do in specific circumstances[5].

It follows that scientists and physicians