

with the three-finger readers differing significantly from the one-finger readers ( $P < 0.02$ ) and sighted controls ( $P < 0.008$ ), whereas the latter groups were not significantly different from one another.

Each of the three-finger readers had a strong tendency to misidentify which finger was being touched during tactile sensory threshold determination, although there was no difficulty in determining that one of the fingers had been touched. In contrast, none of the sighted subjects and only one of the one-finger readers reported such difficulties. Again these are significant differences (for the three groups,  $P < 0.005$ ; three-finger against one-finger,  $P < 0.02$ ; three-finger against sighted,  $P < 0.008$ ; Fisher's exact test, 2-tailed). Sensory threshold testing was also conducted in five other sighted individuals, none of whom had difficulty in localizing tactile stimuli.

A striking feature of the data was the coincidence between the digital topographic disorder in the cerebral cortex and the mislocalization of tactile stimulation of the fingers. This relationship was significant when the data from all individuals were pooled (Fisher's exact test,  $P = 0.017$ ). For the three-finger Braille readers, the hand opposite each of the hemispheres in which there was disorder exhibited a corresponding tactile mislocalization.

'Smearing' of the digital cortical representation could be adaptive for Braille readers who use three fingers in that it serves to fuse input transmitted over different fingers, so that the incoming information can be processed as a whole. Thus, use-dependent cortical reorganization can be associated with functionally relevant changes in the perceptual capacity of the individual.

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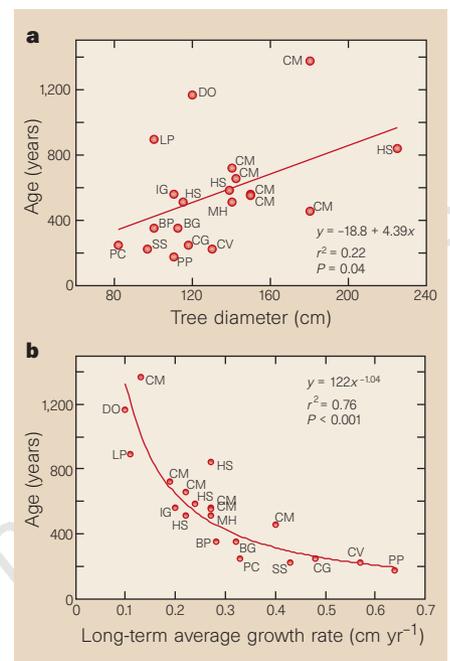
## Ancient trees in Amazonia

The ages of tropical rain forest trees provide critical information for understanding the dynamics of tree populations, determining historical patterns of disturbance, developing sustainable forestry practices and calculating carbon cycling rates. Nevertheless, the ecological life history of most tropical trees is unknown and even the ages of the largest trees remain to be determined. Tree ages are typically measured by counting annual rings, but in tropical forests rings can be non-existent, annual or irregular<sup>1</sup>. In the absence of annual rings, <sup>14</sup>C dating is the only way to determine the age of a tree directly. We have <sup>14</sup>C-dated twenty large, emergent trees from a central Amazon rain forest and find that, contrary to conventional views, trees in these forests can be more than 1,400 years old.

There is debate over how ages are distributed in rain forest trees, although there are almost no direct measurements. Typically, ages are based on extrapolations from growth or mortality rates compiled from permanent plots where observation intervals are short (usually less than 15 years), compared with the longevity of most trees. Because rates vary within a species, and over time within an individual, age estimates are subject to error. Using permanent plot data for 21 canopy species, a study<sup>2</sup> in Costa Rica calculated that the greatest time required to grow from a diameter of 10 cm to the maximum was 440 years. Another study in Costa Rica estimated that, on the basis of maximum and median growth rates for five emergent species, it would take between 90 and 600 years to reach 100 cm in diameter<sup>3</sup>.

Supporting younger age estimates, it has been suggested that only trees that exhibit optimum growth rates emerge from the canopy, and that most suppressed individuals are destined to die<sup>4</sup>. In contrast, on the basis of mortality rates, a study in Panama suggested that some trees can live for more than 1,000 years<sup>5</sup>. Our understanding of tropical tree age demographics can be advanced by measuring ages directly, yet the only previously <sup>14</sup>C-dated tree in the Amazon is a 500-year-old<sup>6</sup> Brazil nut tree (*Bertholletia excelsa*) that is 225 cm in diameter.

To determine the distribution of ages between some large emergent trees in the central Amazon, we <sup>14</sup>C-dated twenty trees from thirteen species harvested in a 80,000-hectare logging operation near the city of Manaus, Brazil. Some trees were very old, with calibrated<sup>7</sup> ages ( $\pm 80$  years) ranging from 200 to 1,400 years. Tree size was significantly correlated with age, but most variability was accounted for by other fac-



**Figure 1** Radiocarbon dates for central Amazon trees. Measurements were made at the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory. Long-term average growth rates were calculated as diameter divided by age. Although significant, size is not a reliable predictor of age (a). For large trees, growth rate is probably a much better predictor of age (b). Species are: BG, *Bagassa guianensis*; BP, *Brosimum parinarioides*; CM, *Cariniana micrantha*; CG, *Caryocarp glabrum*; CV, *Caryocarp villosum*; DO, *Dipteryx odorata*; HS, *Hymenolobium* spp.; IG, *Iryanthera grandis*; LP, *Lecythis poiteaui*; MH, *Manilkara huberi*; PP, *Parkia pendula*; PC, *Peltogyne catingae*; SS, *Sclerolobium* spp.

tors (Fig. 1a). Long-term average growth rate was highly correlated with age and the relationship was nonlinear (Fig. 1b).

Average growth rates varied from 1.0 to 6.4  $\text{mm yr}^{-1}$ , and within one species alone (*Cariniana micrantha*) rates varied from 1.3 to 4.0  $\text{mm yr}^{-1}$ . This suggests that trees can emerge from the canopy by rapid growth, presumably in gaps; by protracted slow growth; or by some combination of both, and the strategy is probably highly species-dependent. At a larger scale, ages for the oldest trees in a region set the minimum time since the last catastrophic disturbance. There is evidence that extensive drought, and perhaps widespread fires, linked to large El Niño events occurred in the Amazon basin 1,500, 1000, 700 and 450 years ago<sup>8</sup>. If the central Amazon was affected, some trees must have survived a number of these events.

Age data also provide important information for foresters. If commercial-sized trees are many centuries old, developing sustainable forest management practices that result in limited forest structural changes will require either huge tracts of forests or very long harvest cycles. Finally,

ancient trees have implications for the residence time of carbon in wood. From permanent plot data we know that about 50% of the above-ground biomass is contained in less than the largest 10% of the trees. Thus, although they are few, the largest trees represent a sizeable component of the forest's carbon budget, and the associated carbon can be very old. These results provide a first look at how ages are distributed among emergent trees of the central Amazon, and underscore the importance of age demographics in the ecological structure and function of these forests.

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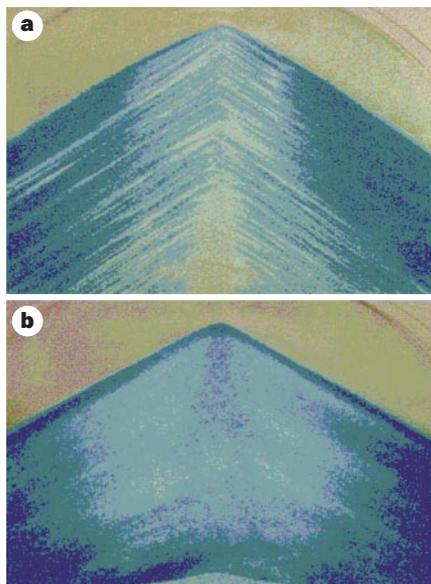
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## Stratification in poured granular heaps

The stratification of poured granular mixtures into layers according to particle size has long been identified as an important mechanism by which such materials segregate<sup>1,2</sup>. The implications of this effect for the process industries have also been discussed<sup>3,4</sup>. Makse *et al.*<sup>5</sup> suggest that stratification takes place only when there is a marked difference in the shape of large and small grains; specifically, when the angle of repose of the coarse phase is much greater than that of the fines. Our experiments show that stratification can occur in the absence of such heterogeneity of particle shapes within the mixture.

We conclude that stratification of granular mixtures is a multidimensional issue. It is first necessary to establish a specific domain of interest within material parame-



**Figure 1** a, Stratified heap formed in slow feeding process; b, well-mixed heap formed in fast feeding process.

ter space. We consider non-percolating granular flows, where the size and density ratios between coarse and fine phases are sufficiently modest to prevent percolation of fines through the coarse phase from being the primary mechanism for segregation. Percolation is known to dominate if the size ratio is sufficiently high<sup>6</sup>. Under these conditions the fine phase drains through the coarse and is found near the bottom of the assembly.

In a series of experiments, we poured a 20-kg mixture of borax pentahydrate granules into a quasi-two-dimensional hemispherical structure (Fig. 1a, b). The structure was 1 m in diameter, with two plates of Perspex separated by a gap of about 9 cm. The granulate had a continuous distribution of sizes from about 0.1 to 1.4 mm. The granules greater than 0.85 mm in diameter were regarded as the coarse phase and were coloured blue; the fine grains were white. The size ratio of the two phases, in terms of  $d_{50}$  measurements, was approximately 2:1 (0.51 and 1.00 mm for fine and coarse phases respectively), and the particle density of each phase was almost identical. The angles of repose of the two phases were 26.9° for the fines and 27.8° for the coarse, so there was negligible difference between the two. The results show that the rate at which material is poured into the structure is a crucial parameter. Figure 1a shows the heap formed in a slow filling process, with a fill time of 45 min (average fill rate 0.007 kg s<sup>-1</sup>). There is marked stratification of the material into layers of fine and coarse. In contrast, Fig. 1b shows the heap formed with a fill time of 25 s (average fill rate 0.8 kg s<sup>-1</sup>). The fine and coarse phases are relatively well mixed, with no stratification.

Stratification thus depends strongly on the fill rate, which parametrizes the overall impact (kinetic energy) of the incident feed stream on the growing heap. This effect has previously been identified for bulk segregation<sup>7,8</sup>. The controlling mechanism is of 'capture' of incident grains by the growing assembly. If the overall impact is high, incident grains can embed themselves within the growing assembly, so their freedom of movement is greatly restricted (provided that the mixture is non-percolating). If capture is relatively inefficient, the grains are relatively free to move, so coarser grains will roll over finer grains and stratified layers will be formed.

Only the efficiency of capture is affected by the shapes of the grains in the two phases. For example, the probability of a large grain's finding a geometrically stable position in which to embed itself, within an assembly of mostly smaller, near-spherical grains, is relatively low. Thus it is not, as has been previously suggested, a necessary condition for stratification that the angle of repose of the coarse grains should exceed that of the fines. Only the range of fill rates for stratification is affected by the particle shape profile within the mixture. If the angle of repose of the coarse grains greatly exceeds that of the fines, stratification will occur over a wide range of fill rates. However, if the feed rate is sufficiently slow, stratification can occur even if the angle of repose of the fines exceeds that of the coarse grains. In a further experiment, not shown here, we increased the overall angle of repose of the fine phase to 32° by adding a higher proportion of very fine material. We again saw stratification, but only under very slow filling conditions.

We are continuing to examine the relative importances of fill rate, size ratio and particle shape for stratification within poured granular mixtures.

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