younger than 24 million years old. The new species of deinothere displays molars that are more 'bunodont' in form (that is, made of several distinct cusplets arranged in transverse crests) than its descendant, whose molars display plain transverse crests. This discovery seems to rule out the possibility that deinotheres are derived from an ancestor bearing plain, transverse-crested molars, as was formerly supposed, and provides new evidence about proboscidean evolution.

Most of our knowledge of Afro-Arabian mammalian communities in the earliest Tertiary has come from the Fayum desert in north-west Egypt. This region has yielded fossil-rich localities ranging in age from about 38 million to 32 million years ago[6,7]. A few other sites, older in age, are known from north-west Africa[8]. All in all, however, places containing evidence of early African mammals are few and far between.

Nonetheless, considerable information has been inferred from the evidence we do have. First, several groups of extant mammals, including proboscideans, sirenians, hyraxes, aardvarks, tenrecs, elephant-shrews and golden-moles, originated on Afro-Arabia, indicating that there was a long period of endemic evolution. This conclusion has been supported by molecular data, leading systematists to unify these mammalian groups into the superorder Afrotheria (a name derived from the hypothesis that they all share a common ancestor and a long history in Africa[9]). Between 55 million and 24 million years ago, African mammalian faunas are dominated by these endemic forms. Only a few other mammals, such as rodents[10] and primates[11], and a group known as anthracotheriid artiodactyls[12], which migrated during limited dispersals from adjacent continents, lived alongside these afrotheres. The rapid evolution of these newcomers led to early speciation on the Afro-Arabian landmass: the catarrhines[13], a branch of primates ancestral to both hominoids and Old World monkeys, are one such case.

The Chilga mammals also yield insights into the dynamics of the faunal interchange between Afro-Arabia and Eurasia. As with the great American interchange, which occurred when the emergence of Central America in the late Tertiary brought North and South American mammals into contact[14], the ensuing ecological competition ended with winners and losers. In this case, the peculiar *Arsinoitherium* appears to be documented for the last time. Hyraxes, which underwent a remarkable diversification[3] in Afro-Arabia during the early Tertiary and occupied the ecological niches of other of the continent's herbivores, were greatly reduced in diversity. Proboscideans, by contrast, which had already started to undergo evolutionary radiation, continued to diversify, and the new land bridge offered them a unique opportunity to carry the

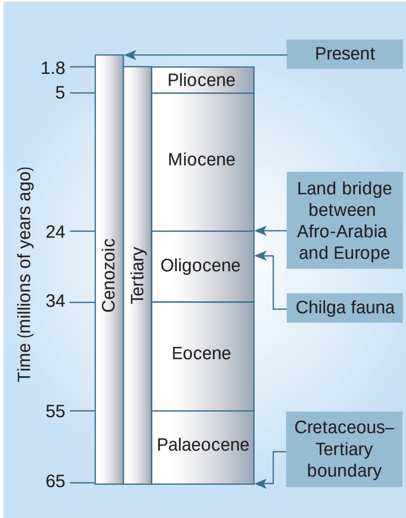

Figure 1 **Timeline: the Tertiary period, and date of the Chilga fauna, in context.**

process into Eurasia and, later, the Americas.

Finally, the discoveries of Kappelman *et al.*[5] highlight two other palaeobiological issues. First, on northern continents glaciation caused a significant cooling around 33 million years ago, which resulted in numerous extinctions among mammalian communities[15]. From these new data, however, it seems that large Afro-Arabian herbivores were not affected, either at that time[16] or later, implying that the climatic changes were less severe on southern continents. Second, the fossil record of the Afro-Arabian continent is not only scanty but also largely concentrated on the northern edge. This has led to the proposal that other groups of mammals existed in Afro-Arabia during its period of isolation, but that they were restricted to more southern latitudes. However, the Chilga mammal community is rather like that found at Fayum in Egypt, which is some five million years older, providing hints that there was little provinciality among Afro-Arabian mammals at that time. As yet, though, we have unveiled only a few of the secrets of mammal evolution on the Afro-Arabian continent. Many more surprising discoveries are to be expected. ■

Jean-Jacques Jaeger is at the Institut des Sciences de l'Evolution, Université Montpellier II, CC64, Place Eugène Bataillon, 34095 Montpellier, France.
e-mail: jaeger@isem.univ-montp2.fr

1. Smith, A. G., Smith, D. G. & Funnel, B. M. *Atlas of Mesozoic and Cenozoic Coastlines* (Cambridge Univ. Press, 1994).
2. Shoshani, J. *et al.* in *The Proboscidea: Evolution and Palaeoecology of Elephants and Relatives* (eds Shoshani, J. & Tassy, P.) 57–75 (Oxford Univ. Press, 1996).
3. Rasmussen, D. T. & Simons, E. L. *J. Vert. Paleontol.* **20,** 167–176 (2000).
4. Jolivet, L. & Faccenna, C. *Tectonics* **19**, 1095–1106 (2000).
5. Kappelman, J. *et al. Nature* 4**26,** 549–552 (2003).
6. Simons, E. L. & Chatrath, P. S. in *Proc. Egyptian Geol. Surv. Centennial Conf. Spec. Publ. Geol. Surv. Egypt* **75,** 775–783 (1998).
7. Gingerich, P. D. *J. Hum. Evol.* **24,** 207–218 (1993).
8. Tabuce, R. Thesis, Univ. Montpellier II (2001).
9. Stanhope, M. J. *et al. Mol. Phylogenet. Evol.* **9,** 501–508 (1998).
10. Marivaux, L., Vianey-Liaud, M. & Jaeger, J.-J. *Zoologica Scripta* **31,** 225–239 (2002).
11. Seiffert, E. R., Simons, E. L. & Attia, Y. *Nature* **422,** 421–424 (2003).
12. Ducrocq, S. *Stuttgarter Beiträge zur Naturkunde B* **250,** 1–44 (1997).
13. Seiffert, E. R. & Simons, E. L. *J. Hum. Evol.* **41,** 577–605 (2001).
14. Lessa, E. P., Van Valkenburg, B. & Farina, R. A. *Palaeogeogr. Palaeoclim. Palaeoecol.* **135,** 1–4, 157–162 (1997).
15. Prothero, D. R. *Annu. Rev. Earth Planet. Sci.* **22,** 145–165 (1994).
16. Rasmussen, D. T., Bown, T. M. & Simons, E. L. in *Eocene–Oligocene Climatic and Biotic Evolution* (eds Prothero, D. R. & Berggren, W. A.) (Princeton Univ. Press, 1992).

Condensed-matter physics

Illuminating behaviour

Marc Bockrath

In fewer than three dimensions, the behaviour of electrons in metals should change to that of a 'Tomonaga–Luttinger liquid'. A photoemission study of one-dimensional carbon nanotubes supports this prediction.

Paraphrasing P. W. Anderson's famous phrase[1] that "more is different", many nanoscience researchers have come to the conclusion that "less is different", at least when it comes to the size of materials. Materials of greatly reduced dimension often behave in qualitatively different ways from their macroscopic counterparts. Much of this new behaviour arises in systems so small that the conduction electrons are no longer free to move in all three dimensions but are effectively confined to lower-dimensional spaces. In these low-dimensional systems, the effects of interactions between electrons can lead to fascinating new phenomena not observed in higher dimensions.

On page 540 of this issue, striking results are reported by Ishii *et al.*[2] from photoemission studies of carbon nanotubes, which are effectively one-dimensional systems. The data show a marked departure from the behaviour expected for non-interacting electrons, and provide a spectacular demonstration of the effects of interactions in low-dimensional systems.

Theoretical calculations indicate that, in a one-dimensional electron system such as a single-walled carbon nanotube (SWNT), the electrons exist in a state called a Tomonaga–Luttinger liquid (TLL)[3]. In a TLL, the low-energy excitations of its electrons are collective and sound-like, involving the correlated motion of many electrons, rather than the single-electron-like excitations found in conventional three-dimensional metals. This has profound effects on many properties of the system. One such property is the 'single-particle spectral function', a quantity that is used to predict the results of experiments when an electron is suddenly added to or removed from an electron system. For a three-dimensional metal, the spectral function is expected to be nearly constant near the Fermi level (the surface of the electron sea, at zero temperature). In contrast, in a TLL, this addition or removal becomes difficult for electrons near the Fermi level, because it requires a complex rearrangement of all the other electrons in the system. As a result, the spectral function approaches zero at the Fermi level, following a power law with an exponent that depends on the strength of the interactions in the TLL. These interactions are conventionally parametrized by a dimensionless constant g, ranging between zero and one for repulsive interactions.

Numerous experiments to probe this behaviour have been performed on a variety of one-dimensional systems, from quantum Hall edge states[4] to organic conductors[5]. SWNTs in particular have proved to be an excellent one-dimensional system, because electrons are able to travel large distances inside them without scattering[6,7]. By attaching leads to the tubes, electrons can be injected into them, to probe the nanotube's single-particle spectral function. In such experiments, TLL behaviour should appear as a power-law dependence of the nanotube conductance on the applied voltage or temperature[8,9]. Measurements on small bundles and single nanotubes have been in relatively good agreement with these predictions[10,11]. However, transport measurements necessarily require at least two contacts, and electrons must travel along the nanotubes, potentially complicating the interpretation of the data.

The photoemission experiments of Ishii *et al.*[2] add significantly to the growing body of experimental literature on the subject. In these experiments, photons hitting the nanotubes liberate electrons from the sample. Energy conservation means that electrons that are more tightly bound emerge with less kinetic energy. So measuring the energies of emerging electrons yields a photoemission spectrum that shows how readily electrons at particular binding energies can be knocked out of the sample. As a result, photoemission is a direct probe of the single-particle spectral function.

Ishii *et al.* have used this technique to probe macroscopic quantities of nanotube material, consisting of bundles of 1.4-nm-diameter nanotubes. Each bundle contains a mixture of tubes that are either semiconducting or metallic, depending on the precise diameter and chirality of the individual tubes. For electron binding energies above about 0.3 electronvolts in the photoemission spectrum, three peaks are observed that arise from the nanotube band structure[12]: the lower two binding-energy peaks are generated by semiconducting tubes, and the highest peak by metallic tubes. Careful analysis of the data indicates that about two-thirds of the nanotubes are semiconducting and the rest are metallic.

At low energies, considerations based on band structure predict a constant spectral function, arising from the metallic tubes. However, in sharp contrast, the experimental results show that the photoemission spectrum follows a power law in energy, extrapolating to zero at the Fermi level. The photoemission-spectrum intensity at the Fermi level follows similar behaviour, decreasing as a power law as the temperature is lowered, and extrapolating to zero at zero temperature. This is precisely what is expected qualitatively for a TLL. Quantitatively, the exponent of the power law can be predicted by calculation of the interaction parameter g in nanotubes. Theory predicts that g is 0.2, giving an expected exponent of about 0.4 for an isolated metallic SWNT[8,9]. The experiments show excellent agreement with these calculations — the measured exponent is 0.48. Altogether, this provides an impressive demonstration of TLL behaviour in nanotubes.

It might seem surprising that the results from a heterogeneous mixture of tubes agree so well with theoretical predictions for a single nanotube. There are two factors favouring this agreement. One is that most tubes are semiconducting — the semiconducting tubes are relatively poor conductors that effectively separate the metallic tubes from each other. The other is that the theoretically predicted exponents depend only very weakly on the distance to nearby conductors. So the exponent found for a metallic tube in a bundle should be similar to that of an isolated tube[10].

These striking results represent only the tip of the large iceberg of fascinating properties that have been predicted for interacting electrons in one dimension. For example, such phenomena as spin transport[13] and shot noise[14] are expected to be drastically altered in TLL systems. These, and a wealth of other exotic properties of the TLL, await future exploration. ■

Marc Bockrath is in the Department of Applied Physics, California Institute of Technology, Pasadena, California 91125, USA.
e-mail: mwb@caltech.edu

1. Anderson, P. W. *Science* **177,** 393–396 (1972).
2. Ishii, H. *et al. Nature* **426,** 540–544 (2003).
3. Voit, J. *Rep. Prog. Phys.* **57,** 977–1116 (1995).
4. Chang, A. M., Pfeiffer, L. N. & West, K. W. *Phys. Rev. Lett.* **77,** 2538–2541 (1996).
5. Sekiyama, A., Fujimori, A., Aonuma, S., Sawa, H. & Kato, R. *Phys. Rev. B* **51,** 13899–13902 (1995).
6. Bachtold, A. *et al. Phys. Rev. Lett.* **84,** 6082–6085 (2000).
7. Liang, W. J. *et al. Nature* **411,** 665–669 (2001).
8. Kane, C., Balents, L. & Fisher, M. P. A. *Phys. Rev. Lett.* **79,** 5086–5089 (1997).
9. Egger, R. & Gogolin, A. O. *Eur. Phys. J. B* **3,** 281–300 (1998).
10. Bockrath, M. *et al. Nature* **397,** 598–601 (1999).
11. Yao, Z., Postma, H. W. C., Balents, L. & Dekker, C. *Nature* **402,** 273–276 (1999).
12. Dresselhaus, M. S., Dresselhaus, G. & Eklund, P. C. *Science of Fullerenes and Carbon Nanotubes* (Academic, New York, 1996).
13. Balents, L. & Egger, R. *Phys. Rev. B* **64,** 035310 (2001).
14. Bena, C., Vishveshwara, S., Balents, L. & Fisher, M. P. A. *J. Statist. Phys.* **103,** 429–440 (2001).

Medicine

Taking apart a cancer protein

Pier Paolo Scaglioni and Pier Paolo Pandolfi

Generation of a particular 'fusion' protein is characteristic of one type of leukaemia. But is it in fact the cleavage of this protein into smaller parts that is important? Provocative new findings suggest that it is.

Cancers develop when genetic mistakes accumulate, causing cells to proliferate unchecked and to show a reluctance to die when required. In many human leukaemias, one of the initial genetic errors is a chromosomal translocation: one part of a chromosome fuses with another, creating a composite gene with unusual properties. A well-known example of this occurs in acute promyelocytic leukaemia (APL), a cancer in which promyelocytes — a type of bone-marrow cell that produces certain white blood cells — accumulate in the bone marrow and blood. In most patients with APL, the cancerous cells harbour a chromosome translocation that fuses the promyelocytic leukaemia (PML) gene to the gene for retinoic acid receptor-α (RARα), giving rise to two fusion proteins: PML–RARα and RARα–PML[1]. It had been thought that full-length PML–RARα is required for this cancer to develop. Writing in *Cell*, however, Lane and Ley[2] challenge this concept. They find that this fusion protein is cleaved at several positions by neutrophil elastase — and that eliminating this enzyme in mice offers some protection from APL.

It is generally believed that the chromosomal translocations characteristic of APL — and those in other types of leukaemia — occur in immature blood-cell precursors that can self-renew[3]. In this way, the fusion