

for the development of spinules or other morphological changes that may occur in synaptic plasticity. □

Frances A. Edwards is in the Department of Physiology, University College London, Gower Street, London WC1E 6BT, UK.
e-mail: f.a.edwards@ucl.ac.uk

1. Fischer, M., Kaech, S., Knutti, D. & Matus, A. *Neuron* **20**, 847–854 (1998).
2. Wagner, H.-J. *J. Neurocytol.* **9**, 573–590 (1980).
3. Ter-Margarian, A. & Djamgoz, M. B. A. *Neurosci. Lett.* **147**, 131–135 (1992).
4. Fifkova, E. *Cell. Mol. Neurobiol.* **5**, 47–63 (1985).
5. Geinisman, Y. *Hippocampus* **3**, 417–434 (1993).
6. Edwards, F. A. *Physiol. Rev.* **75**, 759–787 (1995).

Glacial cycles

Jive talking

John Chappell

Assessment of future climatic changes would be more secure if we fully understood the large or rapid climatic changes associated with the ice ages of the past 2½ million years. Because records of past climates become more sparse further back in time, the most closely studied period has been the last glacial period, which commenced about 115,000 years ago, oscillated, reached its climax of 20,000 years ago and ended 7,000–10,000 years ago.

The last ice age may not represent all modes of behaviour of the climate system, however, and one indication of more distant events is the amount of water locked into ice sheets at various times, which in turn is reflected in sea level. Hence the interest of the paper by Rohling *et al.* (page 162 of this issue¹) in which the authors have estimated sea-level lows, or lowstands, of the past 500,000 years. Most notably, they calculate that, during an ice age that peaked about 450,000 years ago (an interval known to stratigraphers as ‘stage 12’ or MIS12), sea level was around –140 m; that is, 140 m lower than it is today.

What that implies is that the quantity of ice at the climax of MIS12 was 15–20% greater than at the peak of the last ice age

(MIS2), when average sea level was about 120 m lower than now. The total ice mass on northern America and Europe in MIS2 was about 1.5 times greater than that covering Antarctica today; the low sea level in MIS12 implies a further quantity of ice which Rohling *et al.* equate with the volume of the present Greenland and West Antarctic ice sheets (about 5–7 × 10⁶ km³). It is interesting to reflect that melting of these two ice sheets today would raise sea level to about +20 m, a level postulated for the interglacial stage (MIS11) which followed MIS12 (refs 2, 3; see Table 1 on facing page). Sea level at –140 m in MIS12 invites the question, ‘Where was the ice?’; and a level of +15 to +20 m in MIS11 asks, ‘What melted?’; with the corollary, ‘Could it happen now?’. Both events warrant close scrutiny.

Rohling *et al.* derive the –140-m sea level of MIS12 using the Red Sea as their gauge (Fig. 1). The Red Sea does not exchange water freely with the Gulf of Aden because of a sill, at a depth of 137 m, at the Strait of Bab-el-Mandab. So the salinity of the Red Sea is driven by evaporation and is critically affected by flow through the strait; salinity should increase if sea level falls. Sediment cores from the Red Sea’s floor contain fossil plankton

that indicate past salinity, but absences of fossils at certain levels, including MIS2 and MIS12, represent episodes when the sea water was too saline for planktonic life. Salt-balance calculations indicate that ‘aplanktonic’ events would occur if the Bab-el-Mandab sill was at about only 18 m; to achieve this, sea level would have to be about 120 m lower than today.

However, the sill appears to have been at greater depths in the past, because increasing proportions of microfauna that tolerate high salinity show that the Red Sea has become progressively more saline over the past 500,000 years. Rohling *et al.*¹ calculate that the Bab-el-Mandab strait was about 20 m deeper in MIS12; so the MIS12 aplanktonic event should represent a sea level of –20 m lower than that of the aplanktonic lowstand in MIS2, when sea level was about –120 m.

Oxygen-isotope data from microfossils in deep-sea cores lend support to this conclusion. The quantity of water locked into ice sheets affects the oxygen-isotopic composition of ‘average’ sea water, because ice sheets are depleted in the heavier isotope, ¹⁸O. Changes in the isotopic composition of sea water are recorded in microfossil carbonate, although temperature also affects the microfossil isotopes. Data from several cores⁴ indicate that melting of ice sheets after the last ice age (MIS2) caused the oxygen-isotope ratio of average sea water to decrease by 1.26‰, representing a sea-level rise from MIS2 to the present of 115–125 m; by comparison, the isotope ratio decreased by 1.44–1.51‰ through the MIS12–MIS11 transition, implying a sea-level rise of 130–150 m (assuming proportionality).

Evidence for past peaks in sea level comes from both the height of fossil reefs and oxygen-isotope data, but support is less strong for a sea-level high of +20 m in MIS11 (inferred from raised reefs at Sumba, Indonesia, and raised beaches elsewhere^{2,3}). Age measurements of the raised reefs and corrections for tectonic uplift have significant uncertainties. These uncertainties are likely to be compounded by isostatic movements, which are vertical earth movements caused by redistributing water from ocean to ice sheets, and have their largest effects on interglacial shorelines when the interglacial is long, as was MIS11, and when the preceding glaciation was large⁵. The oxygen-isotope data are ambiguous here: depletion of 0.1–0.4‰ relative to present values is observed for MIS11 in some (but not all) deep-sea cores^{4,6}, but this could equally reflect significantly higher sea level or a modest temperature increase of up to 1.5 °C.

Determination of sea level in MIS11 recalls Archimedes’ comment — ‘Give me a place to stand and I will weigh the Earth’. We may not yet have found the place to stand.



Figure 1 The Red Sea, which runs southeast to the ‘pinch point’ of the sill at the Strait of Bab-el-Mandab, before opening out into the Gulf of Aden. Rohling *et al.*¹ have used proxies for salinity in the Red Sea to estimate lows in sea level over the past 500,000 years.

APOLLO 17/NASA

Table 1 The relevant ice-age stages, at a glance

MIS12	Peak of an ice age 450,000 years ago. Sea level estimated by Rohling <i>et al.</i> ¹ at 140 m below that at present (−140 m).
MIS11	Interglacial period that followed MIS12, about 400,000 years ago. Sea-level estimate +20 m.
MIS2	Peak of the last ice age, 20,000 years ago. Sea-level estimate −120 m.

Nonetheless, the large rise in sea level after the MIS12 low and the long MIS11 interglacial both appear to differ from most other glacial–interglacial pairs, which is intriguing. The ice ages were strongly regulated by variations of the seasonal distribution of solar radiation (caused by precession of the Earth’s axis and slow variations of both axial tilt and orbital eccentricity⁷). The strength of this pacemaker was relatively weak during MIS11 and at the climax of MIS12, and was also weak at the height of the last ice age (MIS2), when ice volume seems to have been 15–20% smaller than in MIS12.

The contrast suggests that the climate system may be more unpredictable when the pacemaker is weak than when it is strong². For all that we broadly know about the complex interactions between oceans, ice and climate⁷, climatic behaviour during the ice ages, seen in most detail for the last glacial cycle⁸, is more an imperfectly understood nervous jive than a stately ballet that

gracefully follows orbital forcing.

Rohling and colleagues’ new data¹ from MIS12 tell us that our knowledge of the climate system is far from complete. The question ‘Where was the ice?’ compels further investigation. The possibility that sea level was up to 20 m higher in MIS11 urgently requires confirmation; if it is confirmed, current knowledge is challenged by the questions, ‘What melted?’ and ‘Could it happen now?’ □

John Chappell is in the Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia.

e-mail: John.Chappell@anu.edu.au

1. Rohling, E. J. *et al. Nature* **394**, 162–165 (1998).
2. Pirazzoli, P. A. *Mar. Geol.* **109**, 221–236 (1993).
3. Howard, W. R. *Nature* **388**, 418–419 (1997).
4. Shackleton, N. J. *Quat. Sci. Rev.* **6**, 183–190 (1987).
5. Lambeck, K. & Nakada, M. *Nature* **357**, 125–128 (1992).
6. Oppo, D. W., Fairbanks, R. G., Gordon, A. L. & Shackleton, N. J. *Paleoceanography* **5**, 43–54 (1990).
7. Imbrie, J. *et al. Paleoceanography* **8**, 699–735 (1993).
8. Watts, W. A., Allen, J. & Huntley, B. *Quat. Sci. Rev.* **15**, 133–155 (1996).

Nanotechnology

A quantum leap for electronics

Lydia L. Sohn

Many recent advances in nanofabrication have fuelled the hope that electronic devices can be shrunk from the current micrometre-length scale all the way down to the single-atom or molecule scale (Fig 1). On page 154 of this issue¹, Scheer *et al.* describe electrical measurements on single metal atoms — the smallest electronic components possible. They show that the conductivity depends on the num-

ber of valence orbitals available in each atom. By pushing devices to such an extreme, novel quantum phenomena — such as single-electron charging effects^{2,3}, or energy-level or conductance quantization^{2,3} — might readily be exploited near room temperature (at present, in devices orders of magnitude larger, such phenomena are manifest only at millikelvin temperatures). And molecule-based technology may yield

ultrafast, ultrasensitive hybridized devices based on materials other than traditional semiconductors or superconductors.

Already, a single C₆₀ molecule has been operated as an amplifier⁴, and a single carbon nanotube has been used to make a transistor that works at room temperature⁵. With a whole new class of electronic devices based on single atoms or molecules entirely within our technological reach, it is an exciting time for physics, engineering, material science, chemistry and even molecular biology. Gradually emerging from this excitement is a new field: molecular electronics.

But the future of molecular electronics depends on answers to a series of fundamental questions. First, what types of atom or molecule should one use, so that they can be integrated easily with the macroscopic world and robust enough to withstand millions of operations per second? (Should it be inorganic, organic or biologically based, for example?) Second, can we identify or develop effective technologies to manipulate these single atoms or molecules with precision, and integrate them into a macroscopic electronic circuit? For some time now, we have turned to the scanning tunnelling microscope (STM), which can manipulate single atoms or small groups of them, given atomically smooth substrates in ultra-high vacuum and at low temperature. The copper ‘quantum corral’⁶ is one of the most powerful illustrations of this technology. But STMs are slow, and limited in terms of strict material and environmental requirements; there might be a better technology — faster, more encompassing, less restrictive.

Third, what are the macroscopic electron-transport properties of molecule-based devices? Finally, and most importantly, what particular molecular or atomic properties determine the electronic properties, such as conductance?

For single metal atoms, Scheer *et al.*¹ give answers to the last two questions. Mainly by

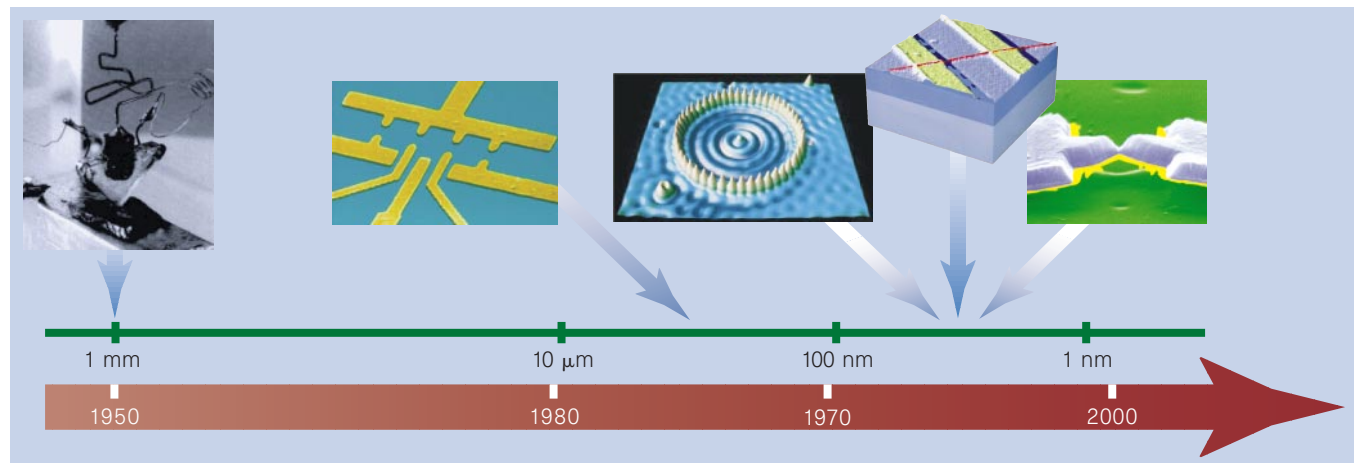


Figure 1 The shrinkage of electronic components. The length scale reached by technology has dropped steadily from the millimetre scale of the early 1950s to the present-day atomic scale. The representative devices, from left

to right, are: the first transistor, a quantum-dot turnstile, a copper ‘quantum corral’, a carbon-nanotube transistor, and the latest — a one-atom point contact.

LUCENT TECHNOLOGIES, BELL LABS/L. KOUWENHOVEN/IBM