cavity and, at the same time, released the head from rigid connection with the trunk to facilitate horizontal and vertical movements.

The sacral part of *Acanthostega*'s vertebral column is only slightly differentiated from the fish-like state, and there are almost no specialized vertebrae that bear sacral ribs for the attachment of the pelvis to the vertebral column. In fish, the pelvis is not connected to the vertebral column, which remains undifferentiated. In tetrapods, walking depends on an effective mechanical connection between the axial skeleton and the ground, so a link between the pelvis and the vertebral column, through the sacrum, becomes an advantage. Just like a fish, *Acanthostega* has a tail-fin, supported by bony rods of dermal origin called lepidotrichia. In contrast to all known lobe-finned fish, however, the lepidotrichia are unbranched and unsegmented.

Coates[2] shows that fish-like characters in *Acanthostega* tend to be concentrated in the posterior parts of the animal, suggesting that the initial stages in the fish–tetrapod transformation concerned the head and anterior parts of the trunk — especially those parts, such as the opercular region and forelimb, that concerned ventilation and locomotion.

As expected, limbs and their girdles were especially strongly affected during the fish–tetrapod transition, but many aspects of the replacement of fins by digits remain unclear. Coates suggests that shorter appendages were more suitable than long paddle-like fins rimmed with lepidotrichia for navigating shallow, vegetation-filled basins[2,5]. A change of function, from exclusively paddling, to a combination of paddling and 'walking' along the bottom, required internal bracing in the form of an enlarged pelvic girdle and elements in the pectoral girdle such as the scapulocoracoid.

At first, the forelimbs were used passively, as props to lift the animal clear of the bottom. Walking ability developed later. The primitive construction of the *Acanthostega* forelimb is revealed in the fish-like proportions of the radius and ulna compared with those of later forms, although some adaptation to tetrapod-like locomotion is revealed by the shape of the humerus. But the wrist bones were not ossified and the ankle joint was absent, although in the contemporaneous tetrapod *Tulerpeton* from central Russia this structure is already evident[7]. Clearly, the evolution of ankle joints and wrist joints lagged behind the formation of digits.

But what of those digits? The traditional textbook view[8,9] sees tetrapods as primitively pentadactyl (with five digits on each limb), with some attempt to trace each digit back to the bony elements in osteolepiform fin-skeletons. This view stood until 1984, when I published[10] an account of the hexadactylous (six-digited) *Tulerpeton curtum*. After that, polydactyly became a matter of interest among students of tetrapod origins. *Acanthostega* manifests an even more primitive octodactylous (eight-digited) condition, and polydactyly is now the rule in all Devonian tetrapods for which digits are known[11]. That polydactyly is primitive fits in well with embryological data[12,13] showing that digit number is not fixed, but relates to the extent of the apical ectodermal ridge zone during ontogeny. The larger the ridge, the more digits are likely to form.

'Transitional' fossils such as *Acanthostega* allow us to work out not only the changes necessary for life on land, but the order in which they occurred. For example, Coates[2] shows that the formation of the tetrapod limb went well ahead of changes in the respiratory system: *Acanthostega* had digits, but it also had fully functional internal gills. But modern lungfish — the closest living relatives of the tetrapods — show that the order in which such changes occurred need not have been inevitable, and that there is more than one way to adapt to life on land. In the African lungfish *Protopterus*, for example, the pectoral fin skeleton remains primitive and, more, becomes greatly reduced, but the lungs are effective. As in *Acanthostega*, the opercular skeleton becomes lost but functional internal gills are retained.

Acanthostega is more primitive in many ways than *Tulerpeton* and another contemporary amphibian, *Ichthyostega*. This implies that not only was it more adapted to life in water, but that it originated directly from water-dwelling ancestors, and indeed may never have moved onto land. Despite this, the mixture of fish-like and tetrapod-like features in *Acanthostega* shows that it is a genuine transitional form which, as such, sheds much light on the transition from water to land. The revival of interest in the fish–tetrapod transition, fuelled by fossil discoveries over the past few years, is continuing, and Coates's monograph on *Acanthostega* will remain the standard work on the subject for many years to come. ☐

Oleg A. Lebedev is in the Palaeontological Institute of the Russian Academy of Sciences, 123 Profsoyuznaya St, Moscow 117647, Russia.
e-mail: olebed@paleo.msk.su

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Daedalus

A radical steam-trap

Electrolysis is the neatest and most controllable of chemical reactions. Its applications are sadly limited by the problem of the electrodes. They are always attacked by discharging ions. Only in a few cases is this tolerable, or chemically useful. Daedalus now has a way out.

He points out that a smooth, red-hot heating element boils water very inefficiently. It becomes completely covered with a thin blanket of steam, through which heat leaks only slowly. Imagine, he says, such an element used as a electrode in an electrochemical cell. Its hot surface would emit electrons readily, like a valve cathode, and so should the hot water surface. Electrons travel quite well through water vapour (the special scanning electron microscope for wet specimens exploits this effect), though to aid their passage the system should be maintained at as low a pressure as possible. Two such electrodes would form an electrolytic cell. Most of its applied voltage would be dropped across the thin steam blankets around the electrodes, but this at least would help to keep them hot. Only a fraction of the voltage would go into electrochemistry; but that fraction would perform wonderful new reactions.

An ion discharged at a steam electrode will, as usual, be converted to the corresponding radical — often ferociously reactive and unstable. But deprived of the normal easy option of attacking the electrode, this radical will vent its energy on the molecules around it. Hydrogen ions will go to that energetic species, monatomic hydrogen. Metal ions will go to isolated metal atoms, hitherto available for chemistry only in the vapour phase. Azide will go to N_3, chlorate to ClO_3, hydroxide to OH — the most ruthlessly reactive of all radicals. All these will attack whatever target molecules the chemists have added to the solution; or failing that, the water itself. The results should be highly entertaining, and even useful. The vast new array of hitherto ignored or unknown radicals will make all sorts of splendid new syntheses possible.

But as a first step, Daedalus wants to use steam electrolysis to purify water. A few ferocious radicals should effortlessly degrade the few parts per billion of dioxin and halocarbons which make environmentalists faint with fear. All the nasties will be instantly mineralized, as the jargon has it. The most dubious piped product will be neatly converted into a chic mineral water.

David Jones