SHUHAI XIAO

Figure 1 **Shot on site — an outcrop of the Ruyang Group in Shanxi Province, China.**

produced from CO_2 by inorganic processes at around the same time. They interpret well-characterized acritarchs, extracted from shales of the Ruyang Group in North China (Fig. 1), as representing the remains of marine organic matter produced during active photosynthesis[3]. The ages of the Ruyang Group rocks are only imprecisely known. But from correlation with the Roper Belt sediments of Western Australia, which contain similar fossil forms[4] and have recently been investigated for sulphur-isotope variability[5], they are estimated to be around 1,400 million years old — that is, mid-Proterozoic in age. Microbes are important players in long-term global biogeochemical cycles, not least by maintaining an oxygen-rich atmosphere through the oxygenic photosynthetic reaction:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

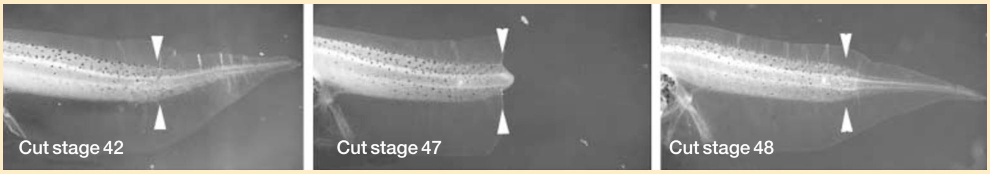
Because a short-circuit exists in the marine carbon cycle, whereby some organic carbon ($C_6H_{12}O_6$) is stored as sedimentary organic matter, a net leakage of oxygen to the atmosphere results. Carbonate carbon and organic molecules are respectively derived from CO_2 through precipitation in water and photosynthesis. Isotopic effects associated with these reactions lead to a fractionation of the $^{13}C/^{12}C$ ratio, between organic carbon and carbonate carbon that is in equilibrium with atmospheric CO_2, of about 25 parts per thousand (25‰). So organic materials are depleted in ^{13}C relative to consanguineous carbonate.

At present, marine photosynthesis responsible for about 99% of primary productivity is performed by single-celled eukaryotic algae using the Calvin cycle[6] — a major pathway for oxygenic photosynthesis. Kaufman and Xiao's approach[2] makes sense, because the source carbon in photosynthesis is CO_2, and the morphologically complex organisms found in the Ruyang shales are reasonably interpreted as eukaryotic organisms that used the Calvin cycle. As a result, it becomes possible to estimate the CO_2 concentration in the system using the magnitude of carbon-isotope fractionation (ϵ_p) between organic carbon and carbonate. This tactic works if the carbon-isotopic composition of individual acritarchs can be measured.

For this purpose, Kaufman and Xiao used an ion-microprobe technique, in which a beam of caesium ions is focused on minute carbonaceous particles to measure their $^{13}C/^{12}C$ ratio at high mass resolution. This is an improvement over attempts to measure carbon isotopes in individual microfossils[7]. Kaufman and Xiao isolated the acritarchs from the Ruyang shales by acid extraction, allowing for rapid repeat carbon-isotope measurements of separate fossils and ensuring

Developmental biology

A tadpole's tale



If tadpoles of the African clawed toad *Xenopus laevis* lose their tail, they can usually make another — but not always. So say Caroline W. Beck and colleagues, who have identified a 'refractory period' during which tails cannot regenerate (*Dev. Cell* **5,** 429–439; 2003). Studies of this down-time have provided insight into the molecular mechanisms that underlie tail regeneration.

The ability to regenerate limbs is scattered throughout the animal kingdom, even occurring in the adults of some species — certain lizards, for instance. But the phenomenon is not well understood at the molecular level. Beck *et al.* have used a variety of new molecular techniques to tackle this question.

The authors started by investigating tail regeneration at different stages of tadpole development. They found that 3 and 7 days into development, at stages 42 and 48, around two-thirds of the tadpoles could regrow their tails after amputation (see picture; the arrowheads represent the position at which the tail was amputated). At stage 49 and beyond, that figure was near 100%. But at stages 46 and 47, only a very few of the tails regenerated (although the tadpoles developed into froglets normally).

What's going on during this refractory period? A look at the regenerating tails showed that a thin skin formed over the cut stump, and that unspecialized cells accumulated beneath the skin; these later began to produce the spinal cord, muscle cells and other cells required for tail formation. This did not occur in the non-regenerating tails.

Proteins involved in the bone morphogenetic protein (BMP) and Notch signalling pathways are required for embryonic tail development. Might they also be expressed in regenerating tails? Beck *et al.* show that they are, but that they are not expressed in tails amputated during the refractory period. If, however, the BMP receptor is forcibly expressed during this period, tail regeneration occurs in nearly all cases. Further findings hint that the BMP pathway activates the Notch pathway to regenerate the spinal cord, but works independently of Notch to regenerate muscle. Whether these molecular events underlie the remarkable phenomenon of regeneration more generally remains to be seen. **Amanda Tromans**