Giant enigma

Strange fossils like nothing alive have been baffling botanists for a century. **Roberta Kwok** reports

WHEN the greening of the land began around 450 million years ago, the first terrestrial plants were tiny. Getting off the ground was a major feat for plants evolved to live in water. In rocks between 420 and 375 million years old, though, giant log-like fossils can be found. The biggest found was more than 8 metres long and a metre wide, and they have patterns like the growth rings of modern trees. But what exactly were they?

The first person to study them, Canadian geologist John William Dawson, thought they were the remains of the first conifer trees – hence the name he gave them in 1859, *Prototaxites*. Not so, scoffed British botanist William Carruthers a decade later, pointing out that the tissue within the fossils was nothing like that of trees. Ignoring all the evidence that they grew on land, Carruthers declared the organism to be an enormous alga – a kind of seaweed, in other words.

For over a century, little changed. "These have been bugging us for over 100 years," says Patricia Gensel, a palaeobotanist at the University of North Carolina at Chapel Hill. Recently, however, there has been a flurry of new studies and ideas.

In the 1960s, the challenge was taken on by Francis M. Hueber, a palaeobotanist then at the Smithsonian Institution in Washington DC. He became fascinated by *Prototaxites* and began travelling far and wide to study them. "I was determined to try to find out what the heck it was," says Hueber, who is now retired.

Because the fossils contain three types of tubes that resemble those in modern fungi, Hueber concluded that the log-like structures were the spore-producing bodies of a fungus –

ROTTED WOOD ALGA-FUNGUS: THE HISTORY AND LIFE OF PROTOTAXITES DAWSON 1859. BY FRANCIS HUEBER. P 146. ©2001. WITH PERMISSION FROM ELSEVIER

a kind of massive mushroom, in other words. He finally published his findings in 2001.

The idea was greeted with "a lot of giggles", Hueber says. It is not quite crazy as it sounds, though. The biggest living organism might be a fungus and although their spore-producing bodies are usually small and short-lived, some do grow larger year after year. The conks of the agarikon fungus, for instance, are hard and woody, and can reach a metre in length. Even so, biologists questioned how a fungus as large as *Prototaxites* could have found enough food to sustain itself when it was far larger than any land plant. Another problem is that Hueber couldn't find any spores or clear reproductive structures.

And what would have made a fungus grow so tall, asked Marc-André Selosse, a mycologist now at the University Montpellier 2 in France. In 2002, he suggested that *Prototaxites* was more likely to be a lichen, a fungus with symbiotic algae. It grew tall to compete with early plants, he proposed, but was shaded out when trees evolved.

Last year, Linda Graham, a botanist at the University of Wisconsin-Madison, proposed an even more radical idea. She knew plants called liverworts could form huge layered sheets with tube-like structures called rhizoids which glued the stack together. Perhaps, she thought, these carpets of liverworts sometimes peeled off the ground or rock, and got rolled up by wind, water or gravity. "I think it's completely reasonable that the world was covered with liverworts at one point in time, and some of them rolled up and formed log-like structures," says Graham. "Makes perfect sense to me."

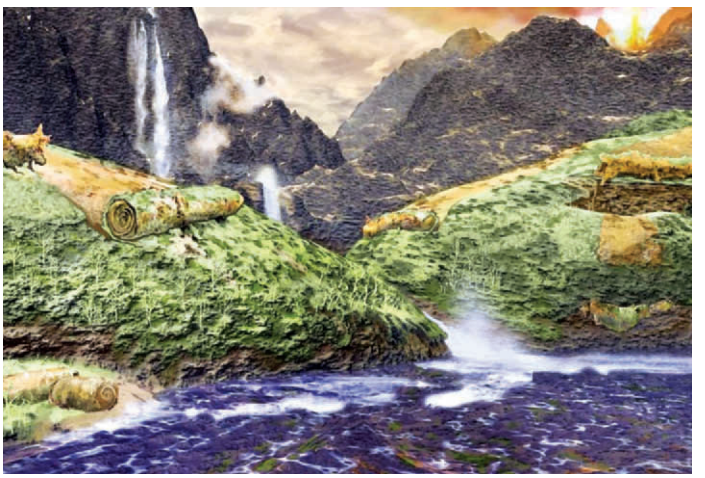
It doesn't to others. "There's no conceivable way that you could roll up something like that," says Kevin Boyce, a palaeontologist at the University of Chicago. "If you watch a tent or a tablecloth blowing in the wind, it doesn't blow into a nice tube. It makes a mess."

To test her idea, Graham let liverwort mats dry and degrade, and then rolled them into cylinders ranging from roughly the size of tiny cigarettes to paper-towel rolls. The liverwort rhizoids ended up resembling the tubes seen in *Prototaxites* fossils, she says.

Rolling produces spirals, points out Boyce, whereas *Prototaxites* fossils have concentric rings. And some specimens have ray-like structures that cut across layers, which are difficult to explain with a rolled structure. What's more, bits of sediment would be picked up during rolling, or fill the gaps between layers during burial, but there is little evidence of this. "It just defies logic," says Thomas Taylor, a palaeobiologist at the University of Kansas in Lawrence.

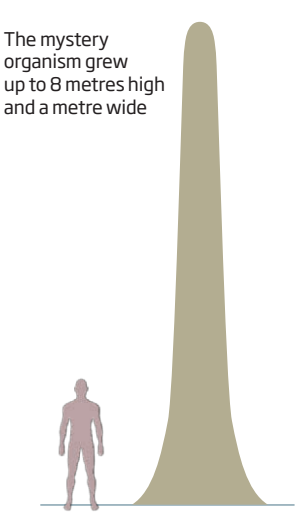
In reply, Graham and her colleagues have pointed to a *Prototaxites* specimen that they say does not look concentric and contains features such as merged rings, which might indicate an uneven spiral (*American Journal of Botany*, vol 97, p 1079). They have also found features that look like bits of debris inside the fossil, although Boyce says these do not appear often enough to support Graham's hypothesis. Graham argues that the liverwort mats could have grown on rocky surfaces and thus would not have picked up much debris.

Then there are the different forms of carbon in the fossils. In 2007, Boyce and his colleagues reported that *Prototaxites* specimens from a single location can vary widely in their carbon isotope signatures, unlike plants. Earlier this year, Boyce showed at least one modern fungus that feeds largely on microbes shows a similarly wide variation – yet more evidence for the fungal hypothesis (*Proceedings of the Royal Society B*, vol 277, p 2149).



It's a wrap? One idea is that the fossils are rolled-up liverworts

Prototaxite height



Graham says these results don't rule out her hypothesis because liverworts can obtain sugars from their environment as well as through photosynthesis, and because fungi and cyanobacteria could be mingled with the liverworts. Both factors would result in variation in isotope ratios. On a landscape with no large plants to get in the way, liverwort mats could have rolled freely, Graham says. "To some extent, I would say it's a failure of imagination," she says of the criticisms.

While Graham has yet to convince others, the fungus case has its problems, too. "There is no one hypothesis that, in my mind, is completely convincing," says Gensel. Settling the issue may take further discoveries.

In 2008, Dianne Edwards, a palaeobotanist at Cardiff University, UK, and her colleagues reported finding casts of relatively large root-like structures from the same period as *Prototaxites*. These structures would bolster the fungus hypothesis if shown to belong to *Prototaxites*, says Edwards. Unfortunately, no fossils with clear tops or bottoms have been found, and virtually all have been transported from their original habitat.

Hueber says some could have been preserved in situ by a volcanic eruption that buried everything in ash, perhaps at a site in New Brunswick, Canada. Gensel plans to look for more specimens in Maine or Canada in the next few years, but she's not optimistic about finding any in their presumed growth position. Graham, meanwhile, plans to search for modern rolled liverwort mats in remote, wind-swept areas.

Of course, it's always possible that everyone is wrong, and that the organism is an anomaly with no modern counterparts. But no one is about to give up yet. "The fossil does exist," says Boyce, "and it had to be something." ■

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KANDIS ELLIOT/STRUCTURAL, PHYSIOLOGICAL, AND STABLE CARBON ISOTOPIC EVIDENCE THAT THE ENIGMATIC PALEOZOIC FOSSIL PROTOTAXITES FORMED FROM ROLLED LIVERWORT MATS AM J BOTANY 2010 97: 268-275