The coelacanth of frogs

S. Blair Hedges

A frog that lives in the mountains of southern India is a rare breed indeed: it is a new species that merits the establishment of a new family. Moreover, this is a discovery with considerable biogeographical significance.

The discovery of a living coelacanth in 1938 captured public attention because it represented an ancient lineage of fishes thought to have been extinct for some 80 million years[1]. Now, a living amphibian with unusually deep evolutionary roots has been discovered in India. Writing on page 711 of this issue[2], Biju and Bossuyt describe this odd-looking species of frog, which was collected in the Western Ghats Mountains of southern India. The characteristics that seem strange to a non-herpetologist — a bloated body, stubby limbs, tiny eyes and protruding snout (Fig. 1) — are not uncommon in burrowing frogs. However, its internal anatomy and DNA sequence data show that this species represents a deep branch in the family tree of frogs. Its closest relatives live in the Seychelles, 3,000 kilometres south of India, near Madagascar. Appropriately, the authors place their new species in a new family.

Just how significant is the discovery of another family of frogs? Only 29 families are known, encompassing the approximately 4,800 known species[3]. Most of these families were named by the mid-1800s, and the last discovery of a species of frog belonging to a new family, as opposed to merely a taxonomic rearrangement, was in 1926 (ref. 3). All others date to the 1700s and 1800s, making this a once-in-a-century find. Moreover, according to fossils and evolutionary 'clocks' devised using molecular data, families of frogs are about as ancient as orders and superorders of mammals, having diverged from one another during the heyday of the dinosaurs in the Mesozoic era (251–65 million years ago)[2,4].

This discovery also draws attention to our incomplete knowledge of biological diversity, even at the higher taxonomic levels. The home of this plump amphibian, the Western Ghats, is one of the eight 'hottest hot spots' of biodiversity in the world[5], meaning that many species occur there that are found nowhere else. Like most other hot spots, it was a region once covered with tropical forests. But pressures from human activities, such as farming, have reduced the forests to less than 10% of their former extent[5].

Biologists are racing to survey and discover species in hot spots before they disappear. Unfortunately, fieldwork can be dangerous (diseases, guerrilla wars, venomous animals), and greater efforts are now required to reach unaltered habitats, such as the tops of mountains. Moreover, some governments are afraid of losing their countries' genetic resources, and have been discouraging foreign scientists from collecting plants and animals. To complete a gloomy picture, taxonomy in general has become an unpopular career choice. Nonetheless, extraordinary discoveries such as this frog show that there is an urgent need for more biotic surveys.

Figure 1 **Star frog: the new species and only member of a newly designated family[2].**

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Of great interest to biogeographers is the finding that the new species is most closely related to Seychellean frogs of the family Sooglossidae. Ocean travel by salt-water rafting is not necessary to explain this relationship, because models of continental drift in the Mesozoic place India and the southern land areas together. The southern supercontinent Gondwana began breaking up 160 million years ago, separating a western continent of South America and Africa from an eastern continent of India, Madagascar, the Seychelles, Antarctica and Australia. Thereafter, the eastern continent continued to break apart, losing Antarctica–Australia (130 million years ago), Madagascar (90 million years ago), and finally the Seychelles (65 million years ago) as India continued northwards. India's collision with Asia, 55 million years ago, created the Himalayas[6–8]. If this geological history is correct, India should have been a 'biotic ferry' with a passenger list of distinctive plant and animal groups that evolved in isolation for tens of millions of years (Fig. 2a).

Oddly, however, the late Mesozoic fossil record of India does not support a biotic ferry model. Instead, it reveals organisms with close relatives in Africa, South America and Asia[7,8], including dinosaurs, lizards, frogs and mammals. Because the geological data allow some flexibility in reconstructing palaeogeography, new models have been proposed that incorporate late Mesozoic land bridges between India and other areas, especially Africa (Fig. 2b,c)[7,8].

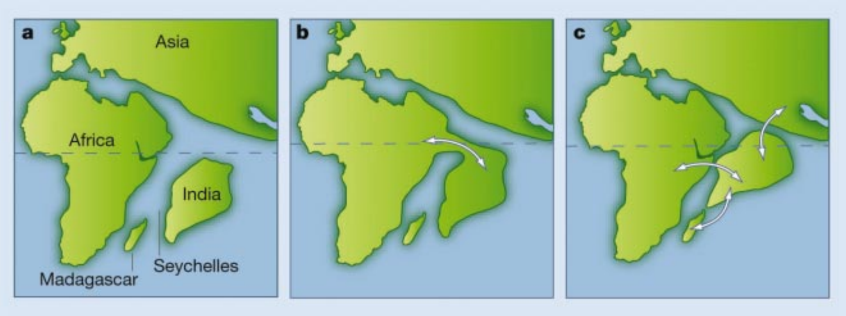

Figure 2 **Possible Indian odysseys: different models for the position of India approximately 65 million years ago.** a, **The standard 'biotic ferry' model showing India isolated by large expanses of water[6].** b, **A limited 'biotic (land) bridge' model incorporating a narrow connection (Greater Somalia) with Africa[7].** c, **Another biotic bridge model assuming a different longitudinal position for India and showing connections with Madagascar, Africa and Asia[8]. The discovery of a new species of frog in India lends support to a biotic ferry model, but the fossil evidence of other animals favours the existence of land bridges.**

How does the new species of frog from India bear on these biogeographical models? If it diverged from the Seychellean frogs (sooglossids) as early as molecular clocks indicate, 130 million years ago[2], continental breakup would not directly explain its origin — India did not split from the Seychelles until 65 million years later. However, the apparent isolation of Biju and Bossuyt's frog family in India supports the biotic ferry model. Molecular-clock studies of other living groups of plants[9] and animals[10,11], including caecilians (limbless amphibians), also indicate that India developed a unique biota during its northward trek.

But why does the current biota reflect such isolation while the late Mesozoic fossils of India indicate past land connections ('biotic bridges')? Perhaps those bridges were more like chains of islands that allowed some — but not all — groups to disperse, as occurred in the past history of plant and animal interchange between North and South America[12].

The discovery of this remarkable new species adds to growing evidence of past isolation in the biogeographical history of India. Nonetheless, it is unclear why India's Mesozoic partner Madagascar lacks some major groups of vertebrates, such as caecilians and representatives of the new frog family, when evolutionary analyses indicate that they should have been there in the past. Clearly, there is a need for more fossil collections and investigation of living faunas, and for refined molecular clocks, to better understand how continental drift influenced India's biota. ■

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Earthquakes

Good tidings

Christopher H. Scholz

Tidal stresses in the Earth's crust don't seem to influence earthquakes. Water wells, on the other hand, seem strangely sensitive to seismic activity. Explanations are now proposed.

The respective absence and presence of two phenomena associated with earthquakes has been puzzling geophysicists for more than a century. One is the general lack of correlation between earthquakes produced by tectonic forces and the 'solid Earth tides', which are caused by the oscillating stresses created in Earth's crust by the gravitational forces exerted by the Sun and the Moon. The other is that some water wells are extraordinarily sensitive to the seismic waves of distant earthquakes. Papers by Beeler and Lockner[1] and by Brodsky *et al.*[2], both in the *Journal of Geophysical Research*, help to explain these phenomena — and perhaps a few others as well.

If earthquakes have simple behaviour, in which stress on a fault builds up to some threshold at which the fault fails, then one would expect their occurrence to correlate with the daily Earth tides. After many increasingly sophisticated studies, no such general correlation has been found. Yet it has been recently recognized that changes in 'static stress' from earthquakes can trigger other earthquakes[3], even when the stress change is as low as 1 kilopascal (ref. 4) — which is roughly the same magnitude of effect associated with Earth tides.

Beeler and Lockner[1] conducted rock friction experiments in the laboratory to simulate the situation of a small sinusoidal loading (the Earth tide) being superimposed on linear loading (a fault being loaded tectonically). The laboratory equivalent of the earthquake cycle is 'stick–slip' events, in which frictional stress builds up at a 'fault' until its adjacent sides begin to slip and a slip instability occurs (Fig. 1a). Beeler and Lockner mapped the amplitude of the oscillating stress necessary to produce correlation with stick–slip events as a function of the oscillation period. They found two regimes. For oscillations with periods greater than a critical time, the correlation amplitude decreases as $1/f$, where f is the frequency of the oscillation. This is just as would be expected from a model — the Coulomb threshold model — which assumes that failure occurs at the peak stress. At periods shorter than the critical time, they found that the correlation amplitudes become frequency independent and are orders of magnitude larger than expected from the Coulomb model (Fig. 1b).

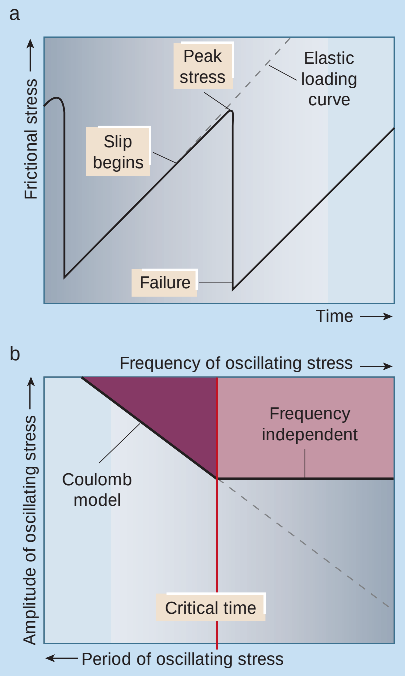

Figure 1 **Stick–slip and Earth tides.** a, **The stick–slip process describes the changing level of frictional stress at a fault over time. Adjacent sides of the fault stick together as frictional stress builds up, but then begin to slip as the rate of stress change starts to diverge from the elastic loading curve. The peak stress value is reached slightly ahead of the point of failure.** b, **Beeler and Lockner[1] looked at the amplitude of oscillating stress, mimicking Earth tides, that reproduces stick–slip events. For oscillations with periods greater than a critical time, the correlation amplitude follows the Coulomb threshold, decreasing in inverse proportion to the oscillation frequency (all scales are logarithmic in this plot). But for short-period, high-frequency oscillations, the threshold for correlation no longer changes with frequency, and is considerably higher than would be expected in the Coulomb model.**

The key point is that the stick–slip instability in rock friction is not abrupt. Rather, it follows a nucleation phase, in which the rate of slip increases as an inverse power law of the time to failure, leading to a peak in stress. Fault failure occurs following the peak. The critical time dividing the two correlation regimes corresponds to the duration of nucleation, which is inversely proportional to the linear stressing rate. This nucleation requires that frictional resistance increases with slip velocity and decreases with slip displacement. Beeler and Lockner have constructed a friction law incorporating these properties — a simple form of rate-state variable friction[5] — and show that it correctly predicts the behaviour in the high-frequency regime.

At periods greater than the nucleation time, the nucleation has no effect. But at shorter periods it greatly dampens the triggering effect, so that much higher amplitudes