

alies in older (3.8 billion years old) crustal rocks from Greenland.

The results obtained by Willbold *et al.* (4) and Touboul *et al.* add to a growing body of work that is revolutionizing our understanding of the deep Earth and early Earth processes through the use of highly precise (to better than ± 5 parts per million) measurements of the daughter products of “extinct” (that is, no longer actively decaying) isotopic systems in carefully selected terrestrial samples. These measurements are at the limit of current analytical capabilities and are far from routine. The ^{142}Nd isotopic variations in ancient terrestrial rocks revealed a record of chemical processing on Earth that started >4.4 billion years ago. The new ^{182}W data push that record back even farther.

As with many new discoveries, the interpretation of the data are contentious. Willbold *et al.* (4) proposed that the anomalous tungsten reflects the composition of Earth’s primordial mantle that predates a “late veneer” addition of siderophile elements (iron-associated elements such as W) to Earth by meteorite influx associated with the Late Heavy Bombardment at ~ 3.9 billion years ago. In that scenario, core formation stripped the mantle of siderophile elements such as W, while ^{182}Hf was still alive, allowing the mantle to accumulate an excess of radiogenic ^{182}W , with late accretion of meteoritic material adding a new supply of siderophile elements (5) and overprinting the early formed signatures.

In contrast, the results of Touboul *et al.* are not in accord with this simple explanation. For example, the Russian komatiites have siderophile element abundances similar to those in the modern mantle source and so cannot be the products of a W-depleted early mantle. This is consistent with previous siderophile element studies of ancient mantle samples showing that by 3.8 billion years ago, Earth’s mantle already had its full complement of siderophile elements and in the relative abundances found in the modern mantle (6).

Touboul *et al.* consider two possibilities to explain the ^{182}W anomalies in the Kostomuksha komatiites. One is that the siderophile element characteristics of their mantle source region were set by metal-silicate partitioning at high temperature and pressure under redox conditions that were more reducing than the modern mantle (see the figure). Under these conditions, the siderophile element partitioning relationships would create a high Hf/W reservoir that could mix with more normal mantle to produce the komatiite source. Alternatively, the

early W-Hf fractionation may be due to crystallization of a magma ocean or formation of an early basaltic crust. These scenarios are difficult to test, but additional integrated studies of short-lived and longer-lived isotopic systems in early terrestrial rocks would provide useful constraints on the timing and importance of core formation, early mantle differentiation, and late accretion.

Regardless of the exact mechanism by which they formed, one question for understanding deep mantle dynamics is how these early isotopic anomalies can be preserved in the mantle for at least 1 to 2 billion years, despite convective mixing and possible overprints from meteorite bombardment. The preservation of anomalies produced during the first 60 million years of solar system history may imply that Earth was never totally molten early in its history and that mixing times were much longer than have been considered to date (7), allowing isotopic signatures to be preserved, perhaps to the present day (8), if we can figure out where to look for them. Sophisticated dynamical models of mantle mixing, coupled with a broader understanding of late accretion and how the interiors of terrestrial planets

respond to energetic events such as large impacts, core formation, and magma ocean crystallization, will be necessary to explain the preservation of such ancient domains.

The studies of Touboul *et al.* and Willbold *et al.* (4) show that we now have the ability to examine processes and events that shaped the deep Earth in the first few tens of millions of years of geologic time. Amazingly, that record still exists if we can learn how to read it. The answers will certainly reveal new aspects of the history, composition, and structure of the early mantle as a key part of understanding the Earth system.

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10.1126/science.1219126

ECOLOGY

Facing Extinction in Real Time

David B. Wake

Amphibian populations worldwide are under threat as a result of additive effects of multiple stressors.

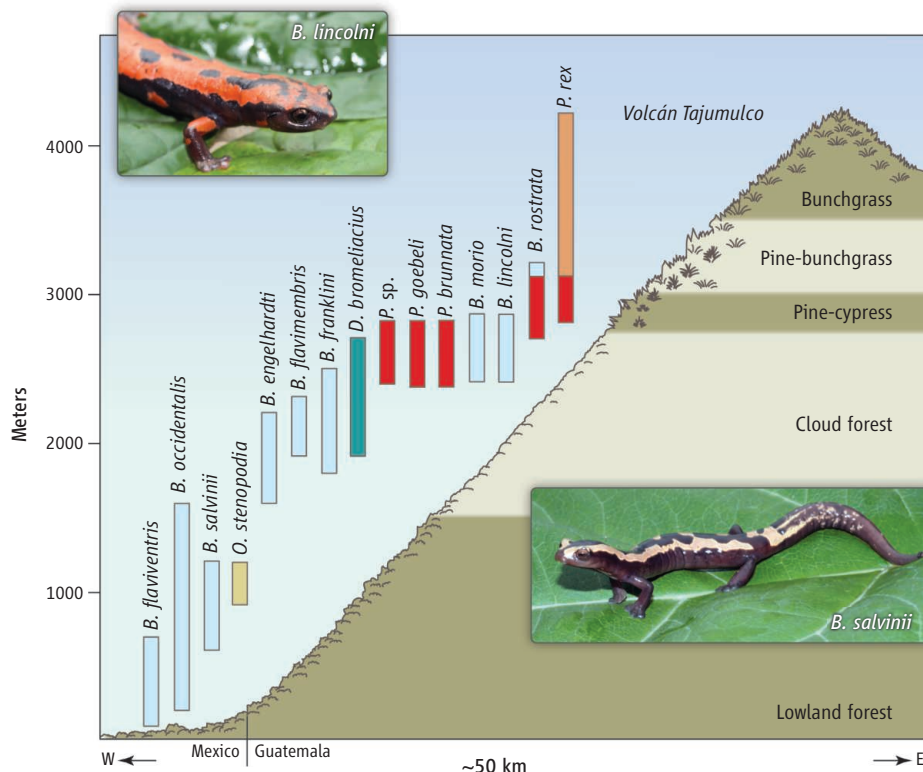
A sense of impending doom has enveloped the community of amphibian biologists for more than two decades, as evidence has built that the subjects of their research are in severe difficulty. What at first was a puzzle based mainly on anecdotes (1) became an evident fact when intensive studies were completed: Throughout the world, amphibians are in decline, and many species—perhaps 40%—face imminent extinction (2). Recent studies have elucidated some agents for amphibian losses and projected the likely prospects for amphibian survival across the globe. The picture that emerges is disturbing.

The amphibian decline is generally acknowledged to be a multifarious problem, connected to factors such as habitat destruc-

tion, climate change, and pesticide use, among others. The discovery in 1998 (3) of a previously unknown infectious agent—a chytrid fungus that kills amphibians—established a new focus of research on amphibian declines. Chytridiomycosis is having a devastating impact on frog populations in Australia (4) and Central America (5). A southeastward wave of chytrid infection in lower Central America (6) has been traced back to the northwest to Monteverde, Costa Rica, at the time of perhaps the best-documented early amphibian disappearance in 1987, and even further north to Veracruz, Mexico, as early as 1972 (7). Despite its recent discovery, the chytrid probably has been adversely affecting amphibian populations for decades.

Hof *et al.* (8) remind us that there are other major factors besides chytridiomycosis in the general decline and paint a gloomy picture for the future of amphibians. The authors project that multiple drivers of extinction

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Nowhere to go. Elevational distributions of salamanders on Volcán Tajumulco, Guatemala, show that between 1978 and 2005 to 2007, three once common upland species disappeared; two others experienced upward range restrictions. Each genus is shown in a different color: *Bolitoglossa*, light blue; *Dendrotriton*, turquoise; *Oedipina*, yellow; *Pseudoeurycea*, orange. Species losses at specific elevations are shown in red.

will become increasingly important, with more intense impacts than previous assessments have found (2). Some regions with high species richness face the greatest risk. Climate change alone is projected to negatively affect as many as 73% of the frog species in the northern Andes and 66% of the local salamander fauna in one part of Central America; taking into account the other variables makes matters worse. The substantial overlap of threats in areas of high species richness is troubling.

The authors project a relatively small role for chytridiomycosis, in sharp contrast with much recent thought. However, it remains to be seen how accurate the models used for chytrid will prove to be. Knowledge of the basic biology of fungus is increasing rapidly, ranging from its genetics (9) and ecology (4, 10, 11), to the development of mitigation strategies to maintain wild populations afflicted by chytridiomycosis (12). Chytridiomycosis may be a greater threat, especially in the short term, than the findings of Hof *et al.* suggest.

Over the past decade, the number of known amphibian species has increased by ~25% to nearly 7000. Most of these species are new discoveries with very restricted geographic ranges and are thus likely to be vulnerable to all factors currently threaten-

ing amphibians. Land-use changes are critical, based on my own field experience with Mesoamerican salamanders. Other important factors, such as pollutants and the impact of invasive species, are likely to make matters even worse.

With their moist and seemingly delicate skins, amphibians might be highly susceptible to climate change (13), but they are long-term survivors, having gotten through the end-Cretaceous extinctions and Pleistocene climatic changes (14). Although geographic ranges of amphibians might adjust in response to climate change, just how is unclear. Many amphibians have narrow elevational ranges along altitudinal gradients, with essentially no latitudinal or longitudinal ranges at all; those restricted to near the tops of mountains may experience range collapse under a climatic warming scenario, because suitable environmental conditions no longer exist locally (see the figure) (15).

Early and Sax (13) have projected climate paths, determined by the location of places with suitable climatic conditions during a sequence of time steps in the history of a species, for 15 species of salamanders in western North America between 1990 and 2100 C.E. They argue that processes related to range shifts—dispersal and population per-

sistence—can have dramatic effects on range shift forecasts, which result from short-term climatic and population characteristics. The authors show that persistence in the face of climate change, even for as short a time as two decades, would contribute importantly to survival, but they think that persistence under unfavorable conditions for so long is unlikely. They conclude that some of the species studied face increased endangerment, while others face probable extinction.

Yet, amphibians may have greater ability to persist than is generally assumed. Phylogeographic studies of widespread amphibians south of the borders of Pleistocene glaciation have consistently found geographically structured genetic variation, which is clear evidence that populations have persisted for tens to hundreds of thousands of years through cycles of climate change (16). Hence, effects of climate change on amphibians may be less predictable than projected in recent research (8, 13).

The main message of the new research on amphibians is that there are additive threats from multiple forcers. This has serious implications. Whether we are studying long-term climatic trends, changes in populations, patterns in human behavior, interactions among diverse factors in infectious disease ecology, or mitigation of stressors, integrative approaches in conservation biology, ecology, and ultimately evolution are essential for understanding and countering the threat to amphibians.

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Science **335** (6072), 1052-1053.
DOI: 10.1126/science.1218364

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