phenomena will be discovered in these nanomaterials.

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No fractals in fossil extinction statistics

Statistical analyses of the fossil record seek to discover the mechanisms controlling biotic diversity throughout the Earth's history. Solé et al.[1] reported that many extinction time series are statistically self-similar, with $1/f$ power spectra, suggesting that extinctions are driven by self-organized criticality or by other scale-free internal dynamics of the biosphere. Here we show that the apparent self-similarity and $1/f$ scaling reported by Solé et al. are artefacts of their interpolation methods. Extinction records that are not interpolated show no evidence of fractal scaling.

Self-similarity and $1/f$ scaling would imply that extinction rates are correlated through time. The problem is that similar correlations are created by Solé et al.'s interpolation techniques. Their raw data are various extinction metrics[2] for 77 stratigraphic stages that range up to 34 million years (Myr) in length. They interpolate between these 77 points every million years, creating time series with 570 points, 86% of which are interpolations rather than real data. The Fourier power spectra and root-mean-square amplitude spectra of the interpolated time series follow power laws with exponents close to one (Fig. 1a,b), markedly different from the exponents expected from uncorrelated, 'white noise' data sets, leading Solé et al. to infer fractal scaling and attribute it to scale-free dynamics of the biosphere.

But uncorrelated white noise is the wrong null hypothesis in this case, because interpolation introduces points that are correlated with one another. A more appropriate null hypothesis is random numbers substituted for each of the 77 real extinction data, associated with the same stratigraphic stages, and subjected to the same interpolation used in the original analysis. We

evaluated this null hypothesis several thousand times (Fig. 1a,b, red curves), and obtained similar results when we applied the same interpolation and analysis methods to the real extinction data[2] used by Solé et al. (Fig. 1a,b, blue histograms). Random numbers without interpolation yielded the expected 'white noise' spectral exponents (Fig. 1a,b, black curves). These results show that Solé et al.'s interpolation methods can generate the fractal scaling they observed.

Solé et al. recognized the possibility of interpolation artefacts, but they also found $1/f$ scaling in ammonoid[3] and planktonic foram[4] diversity fluctuations, with no interpolation (Fig. 1c,d). Their results are incorrect; the actual spectra bear no resemblance to $1/f$ spectra (Fig. 1e,f). Solé et al. may have calculated their spectra from time series of taxon counts rather than extinctions or originations. Taxon counts are integrals of the origination–extinction record, so they will be correlated through time and their spectra will be dominated by long-wavelength variations, whatever the dynamics of extinctions and originations.

None of our results suggests fractal scaling in the extinction record or supports recent models of biotic evolution driven by self-organized criticality[5,6], which predict that such fractal scaling should occur[1].

The fossil record poses special problems[7] for conventional spectral methods[8], which normally require evenly sampled
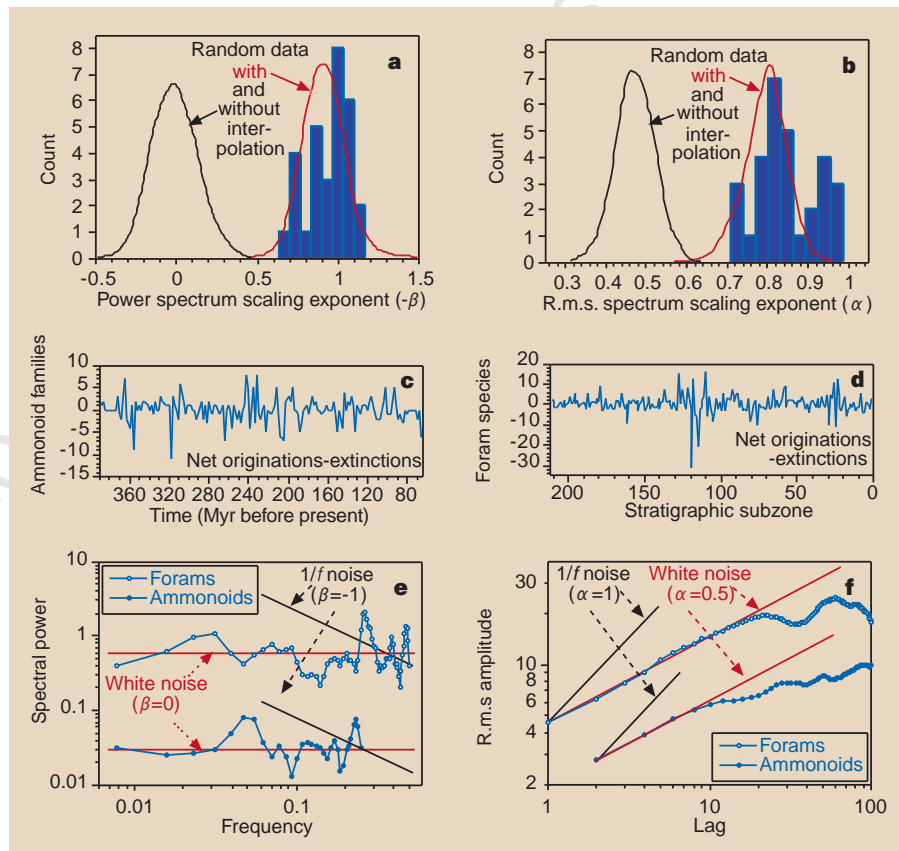
Figure 1 Data analysis. Histograms of fractal scaling exponents for Fourier power spectra (a) and r.m.s. fluctuation spectra (b) for the five extinction measures and six fossil records analysed in ref. 1. Solé et al.'s methods yield scaling exponents close to 1.0, suggesting $1/f$ scaling. The same interpolation and analysis procedures yield similar scaling exponents (red curves) when random numbers are substituted for the real extinction data at each stratigraphic stage boundary. Linear and step-function interpolations give similar results, as do random numbers from uniform, gaussian or log-normal distributions. Random uncorrelated data, without interpolation, give 'white noise' spectra (black curves); small deviations from white noise scaling arise because the data series are short. Time series of ammonoid[3] and planktonic foram[4] diversity fluctuations (c,d) yield power spectra (e) and r.m.s. amplitude spectra (f) that deviate markedly from $1/f$ noise (black lines), and are more consistent with white noise (red lines). The foram data[4] (cited incorrectly in ref. 1) are observations at irregularly spaced stratigraphic subzones, not fixed time intervals. Thus the foram spectra cannot be interpreted conventionally, but we show them because Solé et al. report that they obey power laws. Power spectra were calculated from the Fourier transform (with hanning windowing) of the autocorrelation function for lags from 1 to 256 Myr on detrended time series; scaling exponents were estimated by least squares for $0.01 \leqslant f \leqslant 0.2\ \mathrm{Myr^{-1}}$. Scaling exponents of r.m.s. spectra were calculated for lags from 1 to 30 Myr. Different procedures yield slightly different results, but in each case the results for the real and random interpolated data series are similar. The exponents reported in Table 1 of ref. 1 are more tightly clustered than the exponent histograms shown in a and b here, owing to errors in algorithms in ref. 1 (R.V. Solé, personal communication).

data from statistically stationary processes where the record is much longer than the longest wavelength of interest. Most fossil time series violate all three constraints. The fossil record is our only possible data source for studying the long-term dynamics of Earth's biotic system, but such studies require carefully designed hypothesis tests.

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Arsenic poisoning of Bangladesh groundwater

In Bangladesh and West Bengal, alluvial Ganges aquifers used for public water supply are polluted with naturally occurring arsenic, which adversely affects the health of millions of people. Here we show that the arsenic derives from the reductive dissolution of arsenic-rich iron oxyhydroxides, which in turn are derived from weathering of base-metal sulphides. This finding means it should now be possible, by sedimentological study of the Ganges alluvial sediments, to guide the placement of new water wells so they will be free of arsenic.

As many as a million water wells drilled into Ganges alluvial deposits in Bangladesh and West Bengal may be contaminated with arsenic[1–6]. Measured arsenic concentrations[1–6] reach up to 1,000 μg l^{-1}, which is above the limit set for drinking water in Bangladesh (50 μg l^{-1}) or that recommended by the World Health Organization (10 μg l^{-1}). Consumption of this contaminated water has led to widespread death and disease[1–6].

Arsenic has been reported to derive from the oxidation of arsenic-rich pyrite in the aquifer sediments as atmospheric oxygen invades the aquifer in response to a lowering of the water level by abstraction[4,5]. However, this explanation is not consistent with the following observations[3], made on

46 wells, typical of those in Bangladesh, that were sampled during May and June of 1997: in oxic (shallow) wells, arsenic concentrations are mostly below 50 μg l^{-1}; in anoxic waters, arsenic concentrations ($\leqslant$260 μg l^{-1}) correlate with concentrations of dissolved iron ($\leqslant$29 mg l^{-1}) and bicarbonate (Fig. 1a); and arsenic concentrations increase with depth in wells at Manikganj, Faridpur and Tungipara. These observations suggest that arsenic is released when arsenic-rich iron oxyhydroxides are reduced in anoxic groundwater[6], a process that solubilizes iron and its absorbed load and increases bicarbonate concentration. Sedimentary iron oxyhydroxides are known to scavenge arsenic[7] and, in Ganges aquifer sediments, concentrations of diagenetically available iron ($\leqslant$3.7%) and arsenic ($\leqslant$26 p.p.m.) correlate well[3] (Fig. 1b).

The arsenic-rich groundwater is mostly restricted to the alluvial aquifers of the Ganges delta[3,6]. The source of arsenic-rich iron oxyhydroxides must therefore lie in the Ganges source region upstream of Bangladesh. Weathered base-metal deposits are known to occur[6,8–10] in the Ganges basin (at Bihar, Uttar Pradesh, West Bengal), so weathering of these arsenic-rich base-metal sulphides must have supplied arsenic-rich iron oxyhydroxide to downstream Ganges sediments during Late Pleistocene–Recent times. The arsenic-rich iron oxyhydroxides are now being reduced, causing the present problem. Reduction is driven by concentrations of sedimentary organic matter[3] of up to 6%.

A knowledge of the sedimentary architecture and distribution of iron, arsenic and reductant carbon in Ganges alluvial sediments will allow the development of a predictive model to guide future aquifer
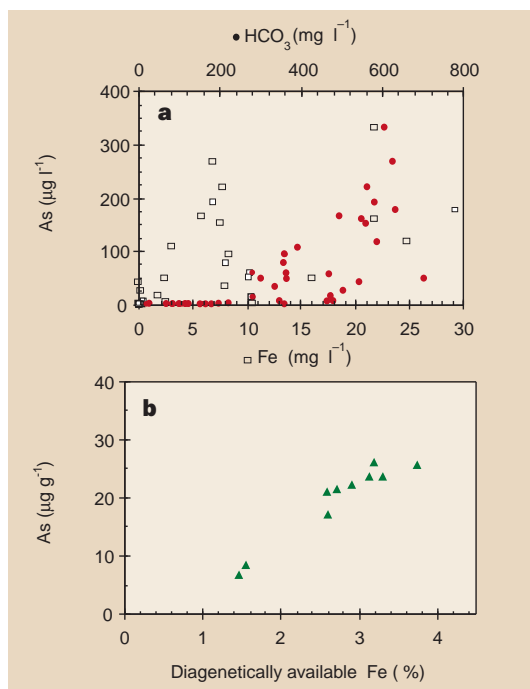
Figure 1 Arsenic chemistry of groundwater and aquifer sediment from Bangladesh. **a,** Arsenic correlates with dissolved iron and with bicarbonate concentrations above 300 mg per litre; the latter is a by-product of iron oxyhydroxide reduction. **b,** Relation of arsenic and iron in aquifer sediments; arsenic concentrations are up to 15 times higher than crustal abundance.

development in a way that minimizes arsenic pollution. Furthermore, as dissolved iron is oxidized it precipitates as iron oxyhydroxide, which scavenges arsenic from solution. It follows that simple aeration of anoxic Bangladesh groundwater, followed by settling, should remove a considerable amount of arsenic from solution. This simple treatment could be performed on a household or village scale. Although the disposal of the arsenic-rich iron oxyhydroxides would require special arrangement, this would be preferable to either the widespread poisoning that now exists or a return to the use of contaminated surface water for public consumption.

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