Beyond polymerase recruitment: Diverse targets of prokaryotic transcriptional activators

Activator	Target in RNA polymerase†
NtrC	σ^{54}
N4 phage SSB	β'
CAP*	α-NTD
Phage λcI	σ^{70}

* The wild-type protein at class II DNA binding sites (*9*).
† At these targets the activator generates an effect on transcriptional initiation at steps other than polymerase recruitment.

tivating eukaryotic RNA polymerases emphasize polymerase recruitment to the promoter and escape from confinement to the vicinity of the transcriptional start site, but ignore polymerase isomerization an available option (*13*). If it really turns out that eukaryotic transcription cannot be controlled at this isomerization step, a possible reason might be that eukaryotic RNA polymerase II does not require isomerization and is recruited to the promoter in a transcription-ready c2-equivalent configuration. That possibility adds particular interest to the prospect of analyzing the mechanics of transcriptional regulation in the *Archaea*. Archaeal RNA polymerases are eukaryote-like in structure and require two eukaryote-like factors for initiation of transcription (*14*). Are archaeal transcription activators also restricted to polymerase recruitment, or do they, like their bacterial counterparts, exploit a wider repertoire of mechanisms?

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GEOSCIENCE

Earthquakes Cannot Be Predicted

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Earthquake prediction is usually defined as the specification of the time, location, and magnitude of a future earthquake within stated limits. Prediction would have to be reliable (few false alarms and few failures) and accurate (small ranges of uncertainty in space, time, and magnitude) to justify the cost of response. Previous Perspectives in *Science* may have given a favorable impression of prediction research, and the news media and some optimistic scientists encourage the belief that earthquakes can be predicted (*1*). Recent research suggests to us that this belief is incorrect.

An earthquake results from sudden slip on a geological fault. Such fracture and failure problems are notoriously intractable. The heterogeneous state of the Earth and the inaccessibility of the fault zone to direct measurement impose further difficulties. Except during a brief period in the 1970s (*2*), the leading seismological authorities of each era have generally concluded that earthquake prediction is not feasible (*3*). Richter, developer of the eponymous magnitude scale, commented as follows in 1977: "Journalists and the general public rush to any suggestion of earthquake prediction like hogs toward a full trough... [Prediction] provides a happy hunting ground for amateurs, cranks, and outright publicity-seeking fakers" (*4*). This comment still holds true.

For large earthquakes to be predictable, they would have to be unusual events resulting from specific physical states. However, the consensus of a recent meeting (*5*) was that the Earth is in a state of self-organized criticality where any small earthquake has some probability of cascading into a large event. This view is supported by the observation that the distribution of earthquake size (see figure) is invariant with respect to scale for all but the largest earthquakes. Such scale invariance is ubiquitous in self-organized critical systems (*6*). Whether any particular small earthquake grows into a large earthquake depends on a myriad of fine details of physical conditions throughout a large volume, not just in the immediate vicinity of the fault (*7*). This highly sensitive nonlinear dependence of earthquake rupture on unknown initial conditions severely limits predictability (*8*, *9*). The prediction of individual large earthquakes would require the unlikely capability of knowing all of these details with great accuracy. Furthermore, no quantitative theory for analyzing these data to issue predictions exists at present. Thus, the consensus of the meeting was that individual earthquakes are probably inherently unpredictable.

Empirical earthquake prediction would require the existence of observable and identifiable precursors that would allow alarms to be issued with high reliability and accuracy. There are strong reasons to doubt that such precursors exist (*10*). Thousands of observations of allegedly anomalous phenomena (seismological, geodetic, hydrological, geochemical, electromagnetic, animal behavior, and so forth) have been claimed as earthquake precursors, but in general, the phenomena were claimed as precursors only after the earthquakes occurred. The pattern of alleged precursors tends to vary greatly from one earthquake to the next, and the alleged anomalies are frequently observed at only one point, rather than throughout the epicentral region. There are no objective definitions of "anomalies," no quantitative physical mechanism links the alleged precursors to earthquakes, statistical evidence for a correlation is lacking, and natural or artificial causes un-

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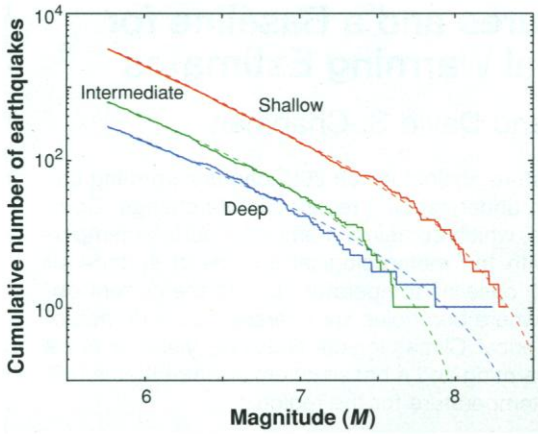
related to earthquakes have not been compellingly excluded (*11*). In other fields threshold signals have often been erroneously claimed as important physical effects (*12*); most if not all "precursors" are probably misinterpreted as well. Unfortunately, each new claim brings a new set of proposed conditions, so that hypothesis testing, which is what separates speculation from science, is nearly impossible.

Chinese seismologists claimed that the 4 February 1975 Haicheng (magnitude = 7.3) earthquake was successfully predicted and that "very few people were killed" (*13*). However, an official publication in 1988 (*14*) states there were 1328 deaths and 16,980 injured. This disparity casts doubt on claims for the Haicheng prediction. China's Cultural Revolution was still taking place in 1975. An American delegation's report (*15*) captures the remarkable atmosphere: "Earthquake prediction was not a minor experiment.... Indeed, belief in earthquake prediction was made an element of ideological orthodoxy that distinguished the true party liners from right wing deviationists." The possibility that political pressures caused inaccuracies in claims for the Haicheng prediction cannot be excluded. An intense swarm of microearthquakes, many of which were large enough to be felt by local residents, began over 24 hours before the main shock (*15*). These microearthquakes might well have induced some spontaneous evacuation. At least 240,000 people died in the 1976 Tangshan, China, earthquake, which was not predicted.



Critical quakes. Number of earthquakes from 1 January 1977 to 30 June 1996 in the Harvard catalog (*24*) with magnitude greater than *M* for shallow (0 to 70 km), intermediate (71 to 300 km), and deep (301 to 700 km) earthquakes. Dotted lines are power-law curves modified by an exponential taper for the largest magnitudes [equation 3 of (*8*)]. Analyses of smaller earthquakes show that self-similarity extends to magnitudes as small as zero (*25*). Such power-law curves are characteristic of systems in a state of self-organized criticality.

Varotsos and co-workers claim to be able to predict earthquakes in Greece on the basis of geoelectrical observations (*16*), but our analyses show their claims to be without merit (*17, 18*). Some of the geoelectrical signals are artifacts of industrial origin (*19*), and there is no compelling evidence linking any of the geoelectrical signals to earthquakes. Controversy lingers primarily because Varotsos's claims have not been stated as unambiguous and objectively testable hypotheses (*20*).

Is prediction inherently impossible or just fiendishly difficult? In practice, it doesn't matter. Scientifically, the question can be addressed using a Bayesian approach (*21*). Each failed attempt at prediction lowers the a priori probability for the next attempt. The current probability of successful prediction is extremely low, as the obvious ideas have been tried and rejected for over 100 years (*17*). Systematically observing subtle phenomena, formulating hypotheses, and testing them thoroughly against future earthquakes would require immense effort over many decades, with no guarantee of success. It thus seems unwise to invest heavily in monitoring possible precursors.

Seismology can, however, contribute to earthquake hazard mitigation. Statistical estimates of the seismicity expected in a general region on a time scale of 30 to 100 years (*22*) [as opposed to "long-term predictions" of specific earthquakes on particular faults within a few years (*23*)] and statistical estimates of the expected strong ground motion are important data for designing earthquake-resistant structures. Rapid determination of source parameters (such as location and magnitude) can facilitate relief efforts after large earthquakes. Warnings of tsunamis (seismic sea waves) produced by earthquakes also contribute significantly to public safety. These are areas where earthquake research can greatly benefit the public.

References and Notes

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