46,000 years ago and northern Australia and Southeast Asia necessarily even earlier (*9*, *10*). Or did our ancestors instead depart from East Africa, crossing the Red Sea and then following the coast of the Indian Ocean (*11*)? A purely coastal "express train" would conveniently explain the early dates for human presence in Australia, but would require that humans were capable of crossing the mouth of the Red Sea some 60,000 years ago. Why, then, was this feat not repeated by any later African emigrants, particularly when the Red Sea level dropped to a minimum about 20,000 years ago?

Ideally, these questions would be answered by investigating ancient fossils and DNA from the Arabian Peninsula. But because this option is currently not available, Thangaraj *et al.* and Macaulay *et al.* have centered their investigation on the other side of the Indian Ocean, in the Andaman Islands and Malaysian Peninsula. Both groups used genetic studies of relict populations known to differ substantially from their Asian neighbors to estimate the arrival time of the first humans in these locations. Thangaraj and colleagues sampled the Andamanese, who were decimated in the 19th century by diseases imported by the British and then suffered displacement by modern Indian immigration (*12*). Macaulay and co-workers sampled the native tribal people of Malaysia, called the Orang Asli ("original people").

Fortunately, the two teams arrived at compatible conclusions. In the Andaman Islands, Thangaraj *et al*. identified the M31 and M32 mtDNA types among indigenous Andamanese. These two mtDNA types branched directly from M mtDNA, which arose as a founder 65,000 years ago. This time estimate for the arrival of M founder mtDNA is matched by that of Macaulay and co-workers. These investigators found mtDNA types M21 and M22 in their Malaysian data set. These M types are geographically specific branches of M that branched off from other Asian mtDNA lineages around 60,000 years ago. Thus, the first Eurasians appear to have reached the coast of the Indian Ocean soon after leaving Africa, regardless of whether they took the northern or the southern route. Interestingly, the adjacent Nicobar Islands do not harbor any old mtDNA branches specific to the islands. Instead, their mtDNA has a close and hence recent genetic relationship (on the order of 15,000 years or less) with the mtDNA of other Southeast Asian populations. This is not unexpected given the more Asian appearance of the Nicobar islanders.

Macaulay and colleagues go two steps further and estimate the prehistoric migration speed of early humans along the coast of the Indian Ocean; they also estimate the likely population size of the emigrant population. Comparing genetic dates of founder types between India and Australia, and assuming a 12,000-km journey along the Indian Ocean coastline, they suggest a migration speed for the first Eurasians of 0.7 to 4 km per year. This value is of the same order of magnitude as genetically dated inland journeys of migrant populations during the last Ice Age, 60,000 to 10,000 years ago (*6*).

One intriguing question is the number of women who originally emigrated out of Africa. Only one is required, theoretically. Such a single female founder would have had to carry the African L3 mtDNA type, and her descendants would have carried those mtDNA types (M, N, and R) that populate Eurasia today. Macaulay *et al*. use population modeling to obtain a rough upper estimate of the number of women who left Africa 60,000 years ago. From their model, they calculate this number to be about 600. Using published conversion factors, we can translate this estimate into a number between 500 and 2000 actual women. The authors' preferred estimate is several hundred female founders. All such estimations are influenced by the choice of parameters and by statistical uncertainty; hence, it is understood that the true number could have been considerably larger or smaller. Improved estimates will involve computer simulations based on informed scenarios using additional genetic loci.

Time is short if researchers wish to secure data on dwindling indigenous populations such as the Andamanese and the Orang Asli. The studies by Macaulay *et al*. and Thangaraj *et al*., which are devoted to the peoples inhabiting the "southern route" along the Indian Ocean, are therefore very welcome. We hope that the new findings will inspire archaeological exploration between the Arabian Peninsula and Southeast Asia in search of the remains of the first Eurasians 50,000 to 100,000 years ago.

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GEOPHYSICS

Past and Future Earthquakes on the San Andreas Fault

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The San Andreas fault is one of the most famous and—because of its proximity to large population centers in California—one of the most dangerous earthquake-generating faults on Earth. Concern about the timing, magnitude, and location of future earthquakes, combined with convenient access, have motivated more research on this fault than on any other. In recent years, an increasing number of sites along the fault have provided evidence for prehistoric earthquakes (*1*, *2*).

Damaging earthquakes are generated by rupture that can span hundreds of kilometers on a fault. Data from many sites must therefore be integrated into "rupture scenarios"—possible histories of earthquakes that include the date, location, and size (length of fault rupture) of all earthquakes on a fault during a period of time. Recently, rupture scenarios for the southern San Andreas fault have stimulated interest in how different scenarios affect interpretations of seismic hazard and underlying models of earthquake recurrence behavior.

Large earthquakes occur infrequently on individual faults. Scientists therefore cannot test recurrence models for damaging earthquakes by waiting for a series of large earthquakes to occur or by consulting instrumental records, which span at most 100 years. Records of large earthquakes must be dug out of the geologic record to characterize earthquakes that predate the instrumental record.

Such studies tend to provide samples of the date and ground displacement at isolated sites along the ruptures, hundreds of kilometers long, caused by large paleoearthquakes. Key insights into fault recurrence behavior have been gained from site-specific data on

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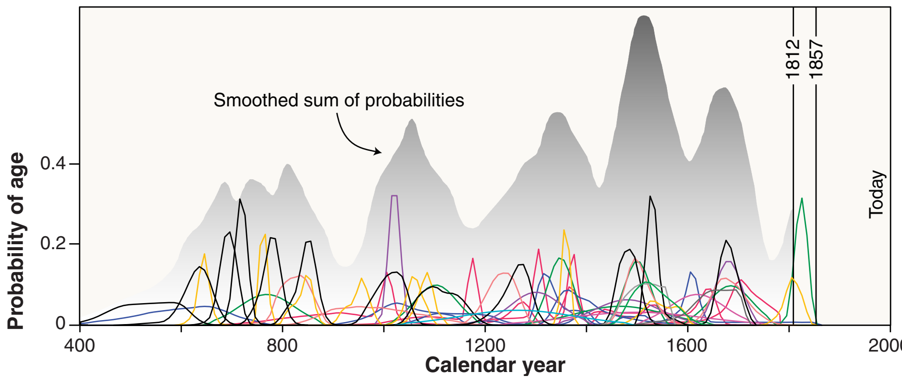


Ruptures on the southern San Andreas fault. Lines are probability density functions for the dates of individual earthquakes, colored by site; the 1812 and 1857 earthquakes have exact dates. Peaks and valleys in the smoothed sum of the individual probability density functions suggest that large parts of the fault rupture every ~200 years in individual large earthquakes or series of a few earthquakes. See (*2*) for site locations and data sources.

the southern San Andreas fault (*3*, *4*). However, measurements of the date and displacement often vary considerably between sites. Further advances in understanding the San Andreas fault will require the construction of rupture scenarios. Given the large body of data and recent advances in interpretive methodology, this goal is now within reach for the southern San Andreas fault.

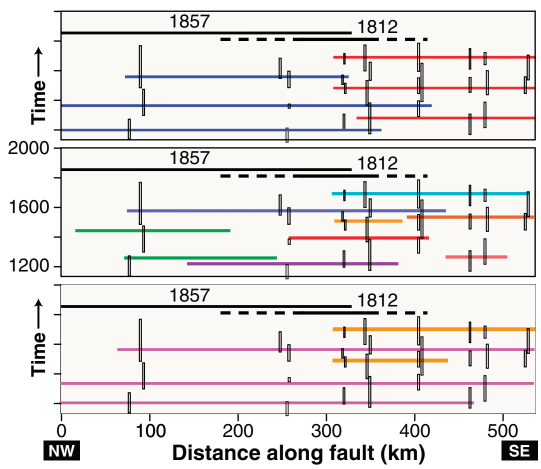
To date, 56 dates of prehistoric earthquakes have been published, based on data from 12 sites on the southern 550 km of the San Andreas fault. There are also about 10 paleoseismic records for the earthquakes of 1857 and 1812. Analysis of these data (*4*, *5*) yields probability density functions of the dates of the earthquakes (see the first figure). These date distributions provide the raw material for correlating ruptures from site to site and the first step toward constructing a history of large earthquakes.

Unfortunately, rupture scenarios based on earthquake date alone are poorly constrained and support a wide range of earthquake models. The existing data can be explained by highly periodic overlapping ruptures (see the second figure, top panel), randomly distributed ruptures (middle panel), and even repeated ruptures spanning the entire southern San Andreas fault (bottom panel). Each model implies a different level of hazard to the Los Angeles region (see the figure legend, second figure) and supports a different physical model of faulting (*2*).

Strong overlap of event dates (see the first figure) may occur when many sites along the fault record the same earthquake or a sequence of earthquakes occur within years or decades. Poor or no overlap may indicate earthquakes with lesser rupture extent or errors in the dating and interpretation of paleoseismic data. Given the rupture lengths of the 1812 and 1857 earthquakes (~150 and 300 km, respectively) and the lack of substantial rupture in the 148 years since 1857, most scientists doubt the possibility of frequent small ruptures on the southern San Andreas fault. Three recent developments strengthen the hypothesis that the fault breaks in relatively infrequent, large earthquakes.

First, the relationship between a displacement observed at a site and the probability of seeing the same rupture at the next site along the fault has been quantified (*6*). Commonly observed displacements of 4 to 7 m (*7*, *8*) imply rupture lengths of more than 100 km (*9*), much more than the distances between paleoseismic sites. Date ranges from nearby sites that overlap poorly are thus likely in error. Second, different chemical, physical, and biological fractions of materials such as peat and charcoal yield very different radiocarbon dates (*10–12*). Because the type of material varies between sites, overlap of dates may be imperfect even if a single rupture spans the sites. Third, careful documentation of evidence from multiple excavations (*8*, *10–12*) shows a wide range in the quality of event evidence from excavation to excavation and site to site. Thus, the evidence for some paleoearthquakes may have been misinterpreted.

A much clearer picture of earthquakes on the southern San Andreas fault should emerge in the next 5 to 10 years. The groups of earthquake date ranges seen every ~200 years in the first figure will probably withstand this reevaluation. Some of these groups contain a single earthquake that ruptured through many sites and may have ruptured large parts of the southern San Andreas fault. Others contain multiple earthquakes at individual sites and could be multiple earthquakes with overlapping ruptures, like the 1812 and 1857 earthquakes (see the second figure). The current 148-year hiatus is probably not exceptional. However, no lull in the past 1600 years appears to have lasted more than ~200 years, and when the current hiatus ends, a substantial portion of the fault is likely to rupture, either as a single long rupture or a series of overlapping ruptures in a short time interval.



Cartoon of rupture scenarios. Black boxes denote paleoearthquake dates at sites along the fault. Black horizontal bars show the extents of the 1857 and 1812 ruptures. Three scenarios accommodate all dates. **(Top)** Ruptures spanning the northern two-thirds of the fault (like the 1857 earthquake) alternate with shorter ruptures centered on the southern third. This model yields a conditional probability of earthquake recurrence of ~70% in the next 30 years, largely due to the long time since a southern event. **(Middle)** Ruptures of variable length recur randomly. This model yields a conditional probability of ~40% in the next 30 years assuming Poisson behavior. **(Bottom)** Long ruptures (violet) span most of the fault, with small additional ruptures (like the 1812 earthquake) (orange) to satisfy all dates. This model yields a conditional probability of ~20% in the next 30 years, assuming quasi-periodic behavior of short and long events.

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