

TECTONICS

Rupture exposed

Great Himalayan earthquakes were thought to rarely rupture the surface. Field analyses in Nepal, however, reveal large surface displacements along the main fault bounding India and Asia during at least two historical earthquakes, in 1255 and 1934.

Thomas K. Rockwell

The front of the Himalaya mountains, the largest continental thrust-fault system in the world (Fig. 1), hosts great earthquakes. Here, the Indian subcontinent is slamming northwards into Asia at a rate of 40–50 mm per year^{1,2}. About 15–18 mm per year of this collision is taken up by India being thrust beneath Asia^{1–3}. This movement is not smooth, however. Instead, strain builds up in the crust and is periodically released in massive earthquakes^{3–5}, as occurred in 1897, 1905, 1934 and 1950, with magnitudes between 7.8 and 8.9. Each earthquake caused tremendous damage, yet none were thought to have ruptured Earth's surface⁶. Without surface rupture, the accumulated strain is not fully released. It has thus been thought likely that even larger earthquakes could occur in the future⁷. Writing in *Nature Geoscience*, Sapkota *et al.*⁸ show that the great Kathmandu, Nepal, earthquake in 1934 did rupture Earth's surface, as did an earlier event in 1255, implying that most or all of the accumulated strain along this section of the collision zone is periodically released.

The population density along the front of the Himalaya mountains is similar to that of New York City. Yet buildings in Himalayan regions are commonly constructed in a less resilient fashion than in places such as California and Japan, where structures are designed specifically to resist earthquake shaking. Thus, both the hazard and risk are high all along this important fault zone, making it important to understand how often these very large earthquakes occur. To assess the magnitude and recurrence time of earthquakes, geologists must delve into the past to identify previous fault movements.

The earthquake history of blind faults that do not rupture Earth's surface can only be inferred from secondary effects, such as landslides, liquefaction of saturated sediments and ground deformation. Such indicators of fault movement can be tricky to identify in the field, meaning that it is difficult to resolve the source fault and determine the length of fault rupture, and thus magnitude of the quake.

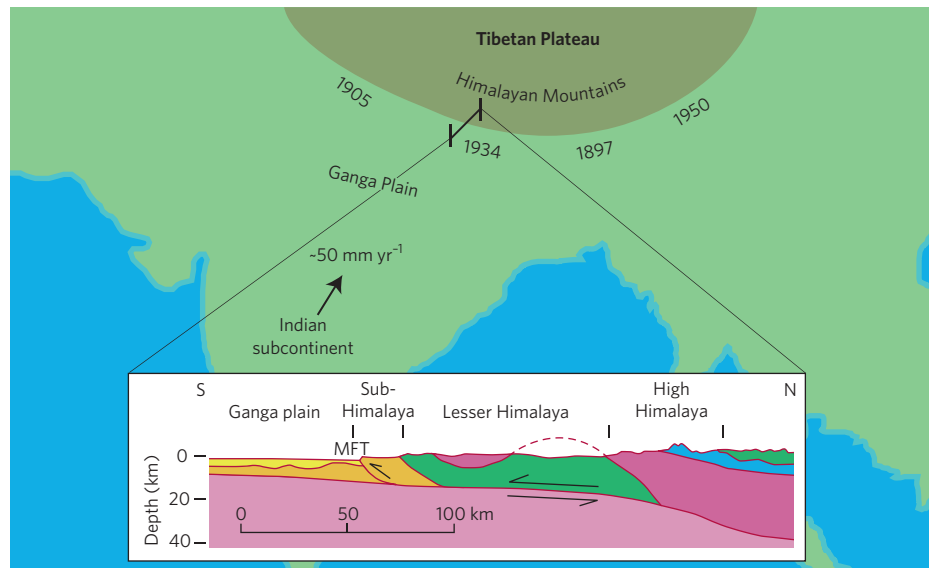


Figure 1 | Cross-section through the Himalayan continental thrust-fault system. The Himalaya mountains have formed in response to the collision between the Indian and Asian tectonic plates. The Main Frontal Thrust (MFT) is the main, currently active fault marking the plate boundary. In the twentieth century, earthquakes on this fault are thought to have been blind, leaving no surface trace. Sapkota *et al.*⁸, however, identify a 150-km-long surface rupture produced by the 1934 earthquake in Nepal, as well as surface rupture produced during a quake in 1255 on the same part of the fault. Image modified from ref. 5, © 2001 AAAS.

It is harder still to determine the timing of earthquakes. The interactions between a fault and the sediments that bury it can provide clues. If a fault breaks to the surface in a large earthquake and is then buried by river or hill-slope sediments, the sediments above and below the top of the fault can be dated to bracket the timing of the earthquake. Without surface rupture, such timings are hard to pin down. Thus, in regions that are prone to blind earthquakes, such as was thought to be the case for the front of the Himalaya Mountains, it is almost impossible to develop long earthquake records.

Sapkota *et al.*⁸ used deformed river sediments and hill-slope deposits, as well as radiocarbon dating of offset river sediments, to assess movement on the Main Frontal Thrust fault in Nepal, the key fault that

currently marks the boundary between the Indian and Asian tectonic plates. They found that this fault had broken the surface along at least 150 km, some time in the past 100 years. The only matching large earthquake occurred in the region of Kathmandu, Nepal in 1934. Furthermore, Sapkota *et al.* identify an earlier rupture on the same fault. This prior movement is probably attributable to the great 1255 earthquake, which is known from historical records to have wiped out one third of the population of the Kathmandu Valley, including the Nepalese King Abhaya Malla⁹.

Identification of the surface ruptures caused by the 1255 and 1934 earthquakes in Nepal demonstrates that great Himalayan earthquakes are not always blind. Elsewhere along the Himalayan thrust front, evidence for surface rupturing earthquakes during the

late Holocene has also been identified^{5,7,10}. Together, these observations suggest that earthquakes of magnitude 8–8.5 are typical for the Himalayan Frontal Thrust. Thus, it is probable that the seismic cycle in this part of the Himalaya is characterized by the release of strain in large earthquakes that do rupture the surface every few hundred years, rather than by the catastrophic release of strain that has been stored over timescales of several thousands of years¹¹.

Sapkota *et al.*⁸ identify the surface rupture for the 1255 and 1934 earthquakes in Nepal,

and establish the minimum rupture length of 150 km for the 1934 event. The full extent of fault rupture is not yet known. Pinning the details of the rupture down in future work could help to develop a more complete view of earthquake hazard in one of the most densely populated seismic zones in the world. □

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PLANETARY SCIENCE

Rising sulphur on Venus

Thirty years ago, the spacecraft Pioneer Venus observed the peak and decline of sulphur dioxide levels above Venus's clouds. Similar observations by Venus Express reveal a surprisingly variable venusian atmosphere.

Larry W. Esposito

Venus is a world astoundingly different from our own. Enormous volcanoes and lava flows cover much of the surface. Although often called Earth's twin due to its similar size, density and nearness to the Sun, Venus is more like an evil twin. The planet is shrouded by thick clouds of sulphuric acid, and its surface is hot enough to melt lead. Our planet-next-door resembles Dante's version of Hell. Understanding Venus and the evolution of its dense, toxic atmosphere is paramount to understanding terrestrial planets such as Earth, including planets we may find orbiting other stars¹. Venus suffers the worst case of global warming in our solar system, an outcome that may be Earth's eventual fate as well², and one that any habitable world must avoid if life is to develop and evolve. Writing in *Nature Geoscience*, Marcq *et al.*³ suggest that the view of Venus's cloud tops over 30 years of spacecraft observations supports a variable venusian atmosphere below.

On Venus, climate and geology are closely linked⁴. Volcanic eruptions fill the atmosphere with sulphurous gases and produce clouds that moderate the greenhouse effect by reflecting sunlight. In less geologically active times that may have occurred in the past, Venus would have been even hotter⁵. Sulphur compounds probably cause the dark markings we see in the Venus clouds today (Fig. 1). The chemistry of the venusian surface measured by the Soviet Venera and VEGA landers in the 1970s and 1980s suggested

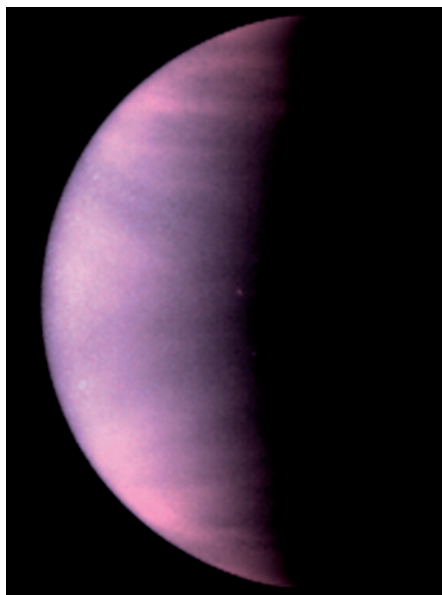


Figure 1 | Venus and its dense sulphur-rich atmosphere as viewed by the Hubble Space Telescope at ultraviolet wavelengths. Marcq *et al.*³ propose that episodic pulses of sulphur dioxide to Venus's cloud tops observed in recent decades by orbiting spacecraft and telescopes are evidence of a variable atmosphere below. It is less clear, however, whether recurring upward transport of sulphur dioxide is due to volcanism or atmospheric circulation patterns.

that volcanoes have erupted within the past million years⁶. The European Space Agency's Venus Express mission, at present

in orbit around Venus, has measured the radiation emitted by the venusian surface and concluded that some volcanoes may have been active within the past 250,000 years⁷.

However, it is unclear how geologically active Venus is today. We know from observations of the surface that Venus is not a geologically dead, crater-scarred object like our Moon. And measurements of an increase in the amount of SO₂ above Venus's cloud tops by the Pioneer Venus spacecraft in the 1970s and 1980s were interpreted as the product of a giant volcanic eruption in the 1970s⁸.

Sulphur dioxide is typically much more abundant below the clouds because sunlight at the cloud top converts it to sulphuric acid. Enhanced mixing, uplift or buoyancy in the atmosphere can transport SO₂ upwards into the view of our telescopes and orbiter spacecraft at the cloud tops. Once injected into the sunlit region above the clouds, the gas is gradually converted to acid droplets, which fall out to form the visible clouds and hazes^{9,10}. This explains the subsequent decline in SO₂ observed by Pioneer Venus in the 1970s and 1980s.

The Pioneer Venus spectroscopic observations and earlier telescopic observations of polar haze were interpreted as evidence for immense volcanic eruptions on Venus in the 1950s and 1970s. The eruptions were thought to provide the buoyancy to lift the sulphurous gases into the visible atmosphere⁸. A similar phenomenon occurred on Earth during