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Moving Earth and Heaven

Colliding continents, the rise of the Himalayas, and the birth of the monsoons

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Therefore will not we fear, though the earth be removed, and though the mountains be carried into the midst of the sea. —*Psalm 46*

As a geologist, I do not fear the processes that carry earth and mountain into the sea. I rejoice in them.

The mountains rise, are lashed by wind and weather, and erode. The rivers carry mud and debris from the mountains into the ocean, where they settle onto the relatively tranquil seafloor and are preserved. The sediments bear evidence about where they came from, what happened to them, and when. By analyzing, measuring, and dating these seafloor sediments, scientists can piece together clues to reconstruct when and how fast their mountain sources rose to great heights millions of years ago, and how the climate and other environmental conditions may have changed in response.

Linking mountains and monsoons

Tens of millions of years ago, a geological process was set in motion that changed the planet. It produced some of the world's most dramatic and extensive mountain ranges. It probably created one of the planet's most intense and important climate phenomena—the Asian monsoons—which today pace and undergird the health and welfare of billions of people in South and East Asia, two-thirds of the total population on the planet. And it may have provoked large-scale environmental changes in the past that brought hominids out of trees and upright onto two feet.

All of these developments in recent Earth history ultimately may be attributed to the land masses now known as India and Arabia, which began moving north some 100 million years ago, on a collision course with what is now Eurasia. According to plate tectonic theory, Earth's crust is composed of interlocking, moving oceanic and continental plates. Scientists consider the collision of the Indian and Eurasian Plates the classic example of how plate tectonics can alter the circulation of the oceans and atmosphere. Here's the hypothetical sequence of events:

The birth of the monsoons

Before the Indian and Eurasian Plates collided, an ancient ocean, called the Tethys Ocean, existed between Eurasia and

Peter Clift

A view of Pangong Lake in the Ladakh region of northern India, taken at an altitude of 18,000 feet, shows the great expanse of the Tibetan Plateau extending high and flat in the background, as far as the eye can see.

Colliding Continents

120 million years ago
The Indian subcontinent was part of a supercontinent called Gondwana. The ancient Tethys Ocean existed between the South American/African and Eurasian supercontinents.

60 million years ago
The Indian subcontinent, moving toward Asia at a speed of 10 centimeters per year, heads toward a collision about 50 million years ago.

Today
The India-Asia collision has closed the ancient Tethys Ocean, created the Himalayan, Karakorum, and Hindu Kush mountain ranges, and uplifted the great Tibetan Plateau.

Africa. By about 55 million years ago, the continents squeezed out the ocean, and some research suggests that the resulting rearrangement of ocean currents may have provoked the strong global warming that came shortly after.

As India smashed into Asia, the world's tallest mountain ranges were thrust up like the hood of a car in a head-on collision. On the Indian Plate, the Himalaya Mountains were formed, spanning Pakistan, India, Nepal, and Bhutan. The Indian Plate was shoved under the Eurasian Plate, uplifting the Karakorum and Hindu Kush Mountains in Afghanistan and Pakistan, as well as the great Tibetan Plateau—an expanse about 4.5 kilometers high and half the size of the continental United States. The creation of this dramatic continental topography launched a cascade of planetary changes.

The Tibetan Plateau acts like a gigantic exposed brick, absorbing summer heat and heating the atmosphere above it. Hot air rises, and cool, moist air—drawn in from over surrounding oceans—rushes in to replace it. That moist air is the source of monsoon rains.

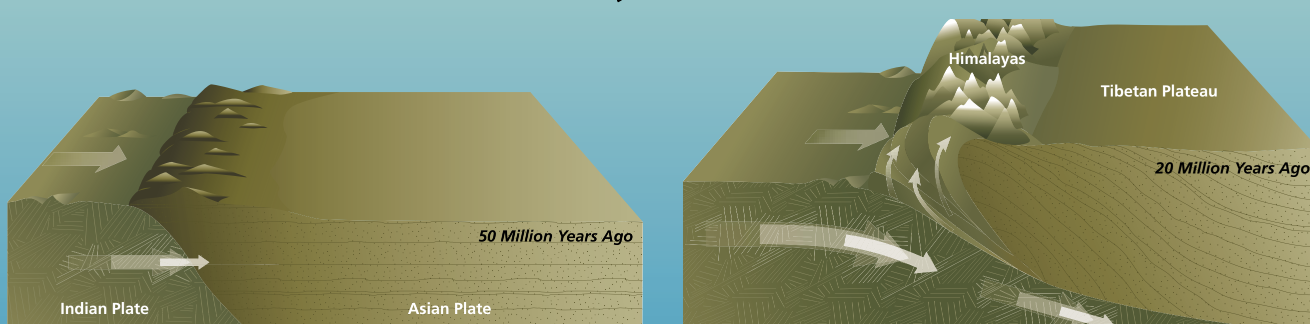
New evidence suggests that between 22 and 15 million years ago, the Asian monsoons may have begun to strengthen. The onset of the monsoons may have been triggered when the Tibetan Plateau reached a threshold height of 2 to 3 kilometers.

Removing CO_2 from the atmosphere

As the mountains rose upward, the land became more exposed to the forces of weather and gravity. Rainwater contains acids that chemically react with rocks. In the process, called chemical weathering, carbon dioxide is drawn out of the atmosphere and converted into carbonate in rocks. As the monsoons strengthened, chemical weathering increased correspondingly.

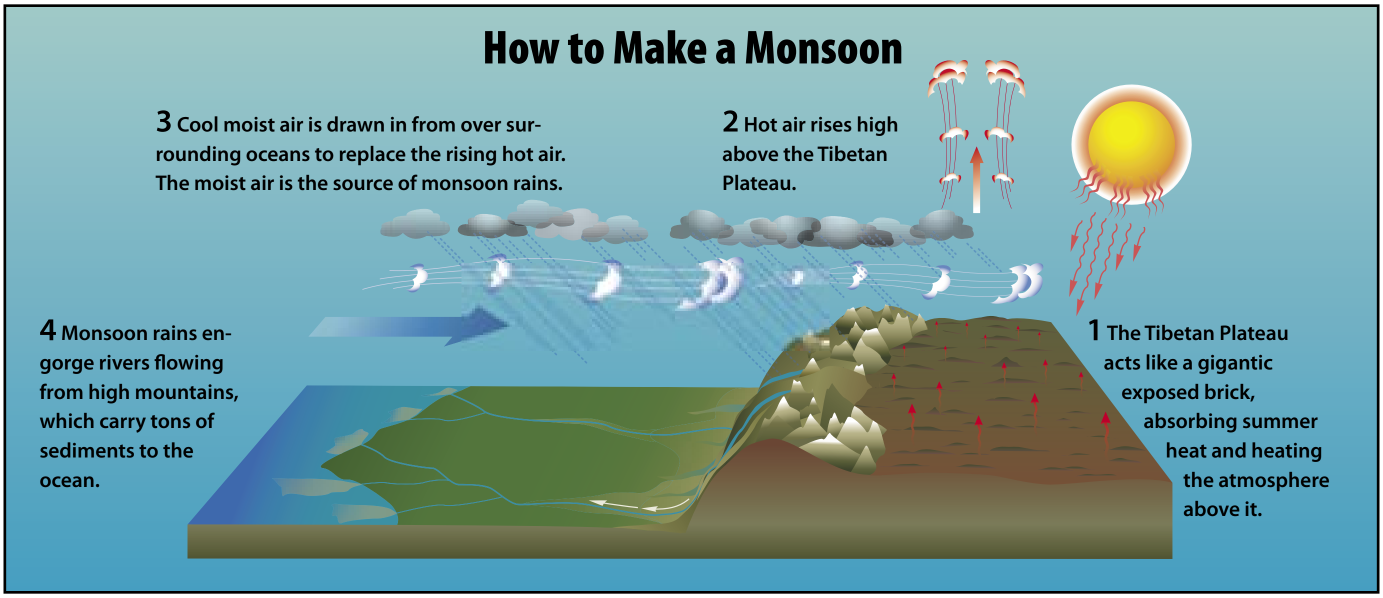
As the monsoon rains increased and the mountains rose, rivers also swelled and cut more deeply into the mountains, increasing erosion and carrying more sediments into the oceans. To give a sense of scale, the Indus River today deposits about 1,000 million tons of mud and sand each

The Rise of the Himalayas and the Tibetan Plateau



In the India-Asia collision, the Eurasian Plate was compressed and thickened to uplift the Tibetan Plateau. The bulk of the Indian Plate continues to be thrust under the Eurasian Plate, further uplifting Tibet. Slices of the Indian Plate were scraped off to form the Himalayas.

Jayne Doucette



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year onto the Indus Submarine Fan in the Arabian Sea. Relieved of such massive sedimentary weight, the mountains could be thrust up higher, in a reinforcing cycle that continued to increase monsoons, erosion, and uplift.

Evolving climates

Climatically, research suggests that the increasing rates of weathering and erosion of the mountains converted large volumes of carbon dioxide from the atmosphere into carbonate sediments that eventually were deposited on the ocean bottom. As carbon dioxide was drawn out of the atmosphere, the global greenhouse effect was reduced, setting the stage for long-term cooling of the planet that culminated in the ice ages of the last 2.7 million years.

In addition, an influx of chemical nutrients into the ocean may have sparked blooms of phytoplankton. Microscopic marine plants also extract atmospheric carbon dioxide via photosynthesis and convert it into carbonate organic matter that settles to the seafloor when the plankton die.

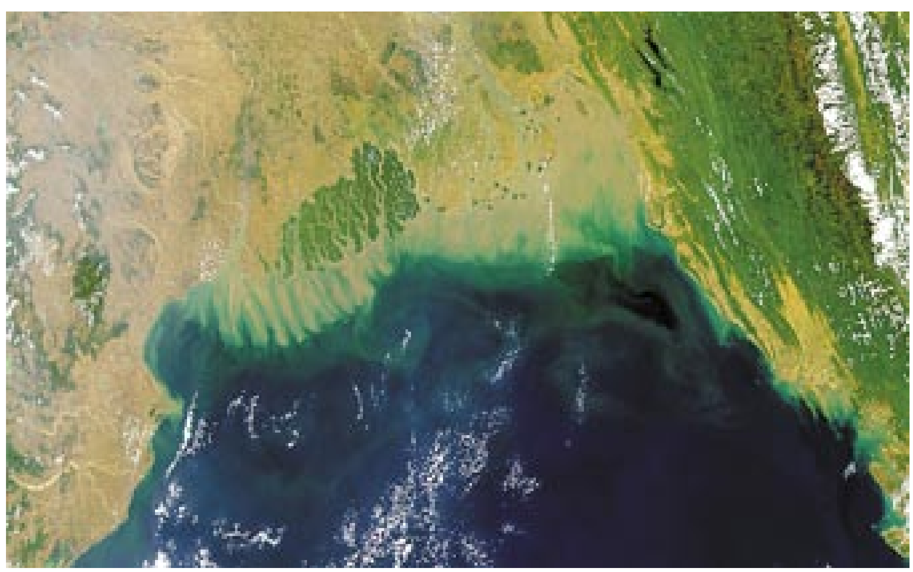
As monsoon winds strengthened, they blew waters laterally across the ocean surface. To replace these waters, cooler, nutrient-rich waters upwelled from the depths to the sunlit surface, providing all the ingredients plankton need to thrive. Evidence from seafloor sediments cores shows an abundance of preserved microscopic shells of plankton (and, by inference, a strengthening of the monsoons) beginning about 8.5 million years ago in the Arabian Sea, though the situation in other parts of Asia is presently less clear.

Evolving humans

Curiously, that same time period marks crucial events in human evolutionary history. The cumulative effects of decreasing atmospheric carbon dioxide reduced the global greenhouse effect, creating a much colder and drier Earth.

About 8 million years ago, paleontological evidence shows that the great apes became extinct in Europe and Asia—victims of a colder, drier climate. They maintained populations only in Southeast Asia and Africa.

About 7 to 8 million years ago, humans began to diverge from great apes in Africa, which, though still equatorially warm, began to dry out. Jungles and forests turned into grasslands and deserts. The climate shift provided evolutionary advantages for bipedal hominids with larger brains to cope with environmental changes.



NASA

An aerial view of the Ganges River Delta shows tons of sediments being poured into the northern Bay of Bengal off India.

Great rivers (the Ganges, Brahmaputra, and Indus) transport large volumes of sediments from great mountains (the Himalayas, the Hindu Kush and the Karakoram) into the ocean. The Bengal Fan extends 2,500 kilometers south into the Bay of Bengal and is 22 kilometers thick. The Indus Fan is 10 kilometers thick and extends 1,000 to 1,500 kilometers into the Arabian Sea.

Continental clues are erased

All this is an intriguing, but speculative, theory.

Unfortunately, our detailed theoretical understanding of Earth's climatic evolution is not matched by a sufficiently detailed record of the evolution of Tibetan and Himalayan uplift and erosion. Theories concerning the uplift of Tibet set the start date anywhere from 65 million years ago to as recently as 2 million years ago.

This lack of consensus principally reflects the lack of a good continental geological record to chart the growth of the mountains. Because of chemical weathering, continental sediments are difficult to date, and erosion often wipes away large and critical portions of the record, destroying any hope for a continuous chronology.

Fortunately, marine sediments preserve robust, continuous records that can link tectonic and climatic evolution. From deep-sea cores, marine geologists have pieced together a detailed record of environmental change in Asia and Africa. Many of those cores have come from the Arabian Sea, the South China Sea, and the Bay of Bengal, which offer fertile territory for examining the interacting histories of the solid earth and its climate.

The great Bengal and Indus Fans

The Tibet-Himalaya region is drained by some of the most vigorous rivers on Earth. The Ganges and Brahmaputra River systems transport large volumes of detritus from the rapidly eroding Himalayas and deposit them in the Bengal Fan in the Indian Ocean. The Bengal Fan is the largest sediment body on the planet; it runs 2,500 kilometers south into the Bay of Bengal and is 22 kilometers thick.

The modern Indus River system drains sediments from the high peaks of the Karakoram, Hindu Kush, and western Tibet. It has created the 10-kilometer-thick Indus Fan, which extends 1,000 to 1,500 kilometers into the Arabian Sea.

Located between the land masses of Arabia and the Indian subcontinent, the Arabian Sea is ideally placed to record the effects of India's collision with the Asian mainland. New data now suggest that the Indus River and Fan system was initiated shortly after India-Asia collision about 55 million years ago, probably in response to the initial uplift of Tibet. This long history makes it a natural storehouse of information on how the mountains developed over long time periods.

An archive buried on the seafloor

Studying this rich store of deep-sea sediments, I have been able to estimate that erosion increased around 16 million years ago, somewhat earlier than the start of the monsoon pattern. That pulse of erosion appears to have been the result of mountain building in the Karakoram.

Conversely, the record shows a decrease in sedimentation rates about 5 to 7 million years ago. Some researchers have proposed this may be related to the strengthening of the monsoons. Increased monsoon rainfall, they speculate, might have promoted the growth of vegetation, stabilizing the slopes and reducing erosion. Other scientists, including me, believe this period was drier, with less rainfall, less erosion, and less seafloor sedimentation.

The marine sediments of the Arabian Sea and the Bay of Bengal hold the promise of allowing ocean scientists to make direct correlations among the evolution of the monsoon, the uplift of the Tibetan Plateau, and the erosion of the plateau by heavy monsoonal winds and rains. With further deep-sea scientific drilling and marine seismic research to reveal sub-seafloor sedimentary layers, we can expose this record in detail and discover how Earth's tectonic, climate, and perhaps human, evolutions are all linked.