Tibet's Tectonic Escape Act

Caught in a closing vise between India and Asia, Tibet may slip out to the side

By RICHARD MONASTERSKY

Like most visitors to Tibet, geoscientist Mark Harrison moved very slowly during his first few days in Lhasa. "I had the feeling I was walking on eggshells," he says. "If I moved too fast, I got lightheaded."

High altitude has that effect on the human body, and Tibet's altitude is extreme. Most of the Tibetan plateau stands more than 5,000 meters above sea level; even the tallest mountain peaks in Europe and the lower 48 states do not reach the average elevation of Tibet's high plains.

This majestic plateau, which has earned the title "roof of the world," plays a central part in one of the greatest geologic dramas unfolding on Earth today: the slow but steady collision between India and Asia.

"What we're seeing is a collision going on between one continent and another on really a substantial scale," says geophysicist Kevin Burke, editor of TECTONICS. "It's very hard to point to another continental collision in the history of the Earth during the last several hundred million years that looks as substantial."

Yet the Tibetan plateau represents a critical enigma for geoscientists. And until researchers understand the region, they cannot claim to comprehend the underlying processes that mold Earth's continents.

On the simplest level, according to the plate tectonics theory, Tibet and the surrounding mountain ranges owe their existence to the Indian-Asian collision. That much geoscientists agree on. But while classical plate tectonics offers much insight into the Earth's surface, the theory fails to explain how continents truly behave. In particular, researchers wonder how Tibet and its environs managed to absorb the tremendous force of the collision.

Paul Tapponnier of the University of Paris and several colleagues have long argued in favor of a process called continental escape, maintaining that India's ongoing push into Asia forces Tibet and other areas to slide to the east and out of India's path, like a watermelon seed squeezed between two fingers. The debate over continental escape has raged for years, but the French researcher believes he has now found the first solid evidence for this theory in the heart of a Chinese mountain range.

In the beginning of the Tibetan drama, the curtain opens on the world of 50 million years ago, when India was an island unto itself. The warm waters of an ancient sea called the Tethys separated this isolated land mass from the giant Eurasian continent. Since then, India has journeyed some 3,000 kilometers to the northeast and has forced its way deep into Asian territory.

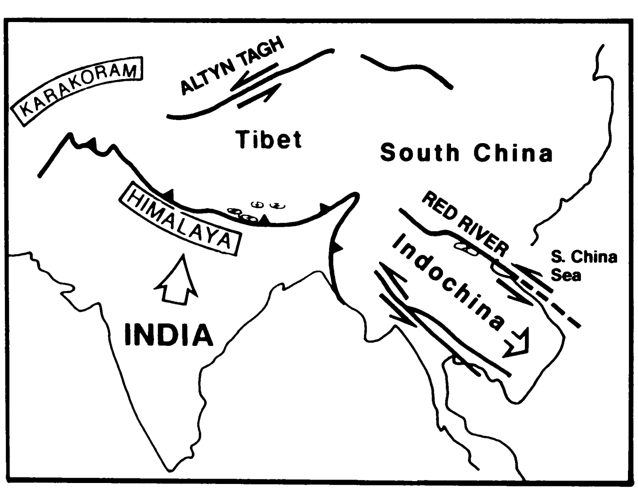
One of the earliest theories concerning the collision came from Swiss geologist Emile Argand in the 1920s. Argand suggested that a large portion of India managed to slide far beneath Asia, thereby raising the vast plateau that stretches northward from central Tibet into neighboring parts of China. Some researchers have revived this theory in various forms during the past two decades, but most don't accept it. "I disagree with [the underthrusting scenario] almost entirely. To me, that's just not mechanically possible," argues Gregory Houseman, a geophysicist at Monash University in Clayton, Australia.

Instead of ducking underneath Asia, India seems engaged in a head-to-head shoving match with the larger land mass – and India is apparently winning, because Asia has suffered the bulk of the damage. Magnetic grains in the rocks of southern Tibet suggest the collision has pushed the original edge of Asia some 2,000 km toward Siberia. To get a sense of that distance, imagine a similar collision closer to home: South America starts moving to the northwest and, over millions of years, shoves the crust of Florida as far north as the present latitude of Lake Superior.

Such a collision does not fit neatly within the domain of classical plate tectonic theory, which defines plates as rigid pieces of Earth's outer shell that do not buckle or bend in the middle. The theory's assumption of strong, unbending plates apparently holds true for the ocean floor, but it doesn't adequately describe how vast regions of a continent can deform during a collision.

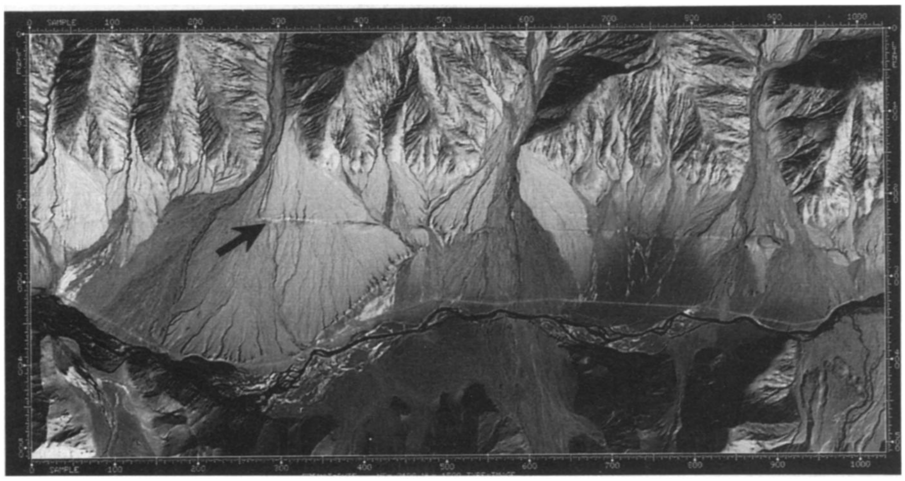
In the case of India and Asia, a look at the map reveals one way in which continental interiors warp. The Tibetan plateau sits amid a swarm of mountain ranges including the Tian Shan, Pamirs, Kunlun and the world's tallest peaks in the Himalaya. Earth scientists believe the growth of these great wrinkles in the Earth's skin partially explains how Asia absorbed the impact from India's crash.

Seismic waves from earthquakes and experimental explosions have revealed another way in which the Asian plate has taken up much of the collision's force. By studying how the waves bounce off the bottom of the crust, seismologists have discovered that Tibet's crust measures some 65 to 80 km thick – about twice the thickness of crust elsewhere on the globe. This suggests the collision has caused Tibet to contract horizontally in the north-south direction while thickening in



Tapponnier

As India plows forward into modern-day Asia, the great Altyn Tagh fault allows Tibet to slide eastward and out of the way. Some think Indochina long ago performed the same type of escape act along the Red River fault, thereby absorbing much of the force from the Indian-Asian collision. The 50-million-year-long crash also raised the Himalaya mountains and created the Tibetan plateau.



Peltzer

Like a scratch on a picture, the Altyn Tagh fault runs straight across this 5-by-10-kilometer zone imaged by the French SPOT satellite. The fault allows Tibet to slide eastward in relation to Siberia, causing land on the bottom half of the image to move to the right of the land on the top half. A 200-meter "step" (arrow) in an ancient river channel demonstrates the direction of movement along the fault. In the Dec. 8, 1989 SCIENCE, Gilles Peltzer and his colleagues suggested that the fault produced this step in the geologically short span of 10,000 years or less, meaning Tibet is moving rapidly to the east.

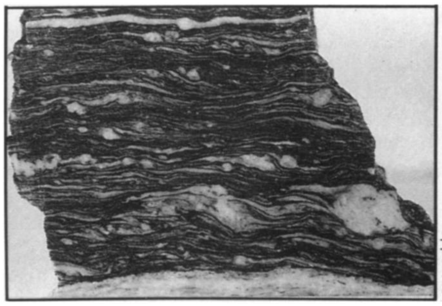
the vertical dimension, almost like a soft cheese squeezed in a small vise.

The theory of continental escape describes a different type of behavior. Tapponnier and Peter Molnar of the Massachusetts Institute of Technology in Cambridge raised this possibility for Tibet in 1975, when they found several extremely large "strike-slip" faults in satellite images of Asia. Strike-slip faults form the border between two blocks that slide past each other, like trains traveling in opposite directions along two parallel tracks.

Molnar and Tapponnier were struck by the scale of the Asian faults. One, called the Altyn Tagh, runs for a length of more than 2,000 km and its trace shows up on satellite images as clearly as that of the San Andreas, the great strike-slip fault in California. The two researchers suggested that strike-slip faults bordering Tibet allow parts of the plateau to "escape" by sliding eastward as India puts the squeeze on Asia.

Fifteen years later, Molnar and Tapponnier stand on opposite sides of a theoretical chasm. Molnar and Philip England of Oxford University think crustal thickening and mountain building play the most important role in the collision, with continental escape assuming minor credit. Tapponnier, citing new evidence, contends escape deserves at least equal billing.

The heart of an ancient fault: Heat and intense shearing forces deep within the Red River fault stretched the minerals in this rock more than 20 million years ago. The direction of the warping indicates that Indochina moved eastward with respect to south China, implying that it escaped from India's path.



Tapponnier

Tapponnier's prospective trump card comes from another great Asian strike-slip fault, called the Red River fault. This crustal crack extends more than 1,000 km from Tibet to the South China Sea and forms the geologic boundary between South China and the Indochinese peninsula, which holds Vietnam, Laos, Cambodia and Thailand.

Along part of the fault in China's Yunnan province, Tapponnier and a team of French, Canadian and Chinese researchers have found twisted metamorphic rocks created during the same time as the collision between India and Asia. To geologists, such rocks signify extremely high temperatures and intense shearing forces. Tapponnier calls them "testimony of a great event."

He and his colleagues suggest in the Feb. 1 NATURE that these rocks formed about 20 km below the surface and provide a vivid picture of what was going on deep within the ancient fault zone during an earlier stage in the collision. They say the mangled state of the rocks and the direction of the twisting indicate that Indochina once lay to the northwest and the fault allowed it to slide southeastward relative to south China. Using the radioactive decay of uranium to lead as a clock, they date the cessation of this motion at about 23 million years ago, during the middle of the ongoing collision.

Last spring, the team discovered more metamorphic rocks along a different stretch of the Red River fault, Tapponnier told SCIENCE NEWS in an interview from Paris. All the rocks suggest Indochina "escaped" to the southeast as India plowed into Asia, he says.

On the basis of the accumulating evidence, Tapponnier and his colleagues conclude: "The occurrence of large southeastward displacement of Indochina relative to South China along the Red River zone during the Tertiary is now beyond doubt."

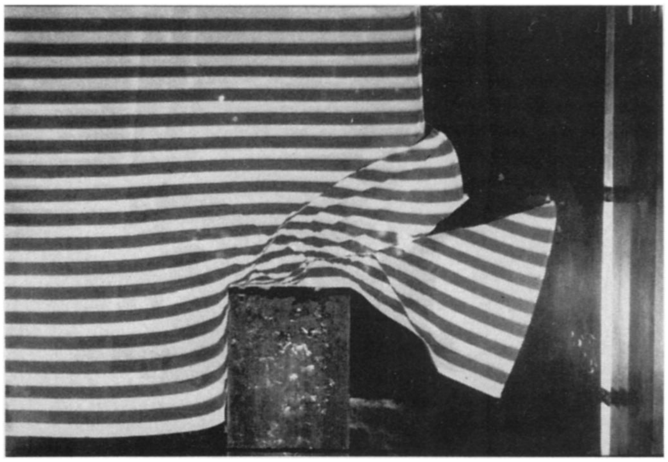
The researchers acknowledge that it's hard to gauge how much escape has occurred along the Red River fault, but they suggest that India has pushed Indochina at least 500 km, forcing it to jut out into the sea. Such a staggering amount of continental escape would have occurred at roughly the same time as the formation of the seafloor in the South China Sea. Tapponnier's group suggests that the sideways escape of Indochina may have opened a new ocean basin, creating the South China Sea. If so, continental escape would have rearranged the entire face of southeast Asia.

The new findings have led these and other researchers to view the Indian-Asian collision as a drama that unfolds in several different acts. At some point in the first act, Indochina escaped along the Red River fault, allowing India to maintain its course. The escape was rapid enough to absorb most of the force from the collision. But Act I ended around 23 million years ago, when the fault became so warped that it locked and halted the continental escape. Act II opened when the stress on Asia grew large enough to thicken the crust, eventually forcing Tibet to rise as a plateau.

Today, in the middle of the third act, continental escape seems active again, this time along the Altyn Tagh fault bordering Tibet's northeast side. The Altyn Tagh has an extraordinarily high rate of slip, measuring 3 centimeters a year in some places – a slippage rivaling that of the San Andreas. Tapponnier sees the Altyn Tagh fault doing what the Red River fault did long ago – carrying material out of the way as India dents Asia at a rate of about 5 cm a year.

"At present, Tibet is moving to the east. There's no question there. And it's moving fast," Tapponnier says.

Recent work by Mark Harrison at the University of California, Los Angeles, supports the idea that the collision has



Peltzer

A laboratory experiment set up to mimic the Indian-Asian collision. As a hard block (India) rams into a striped piece of plasticine (Asia), cracks develop in the plasticine, forcing chunks of material to slide out of the block's path.

Molnar and England say they remain unconvinced that significant continental escape has occurred along the Red River fault zone. In particular, Molnar says the new findings contradict the established geologic maps of the area made by the Chinese.

However, Molnar adds, "To be truthful, I think I will eventually believe what they've done, in general. The reason for not ignoring it is that [their theory] predicted it. That's a pretty strong reason for taking them seriously." Yet even if Indochina did drift southward, the continental collision didn't necessarily drive that movement, he says. Other forces could have pulled Indochina toward the sea.

passed through several stages. Using radioactive elements to determine how rocks have cooled over time, Harrison finds that parts of Tibet and the Himalaya began to rise rapidly at about the same time as the Red River fault jammed and stopped allowing material to slide eastward.

Tapponnier and Gilles Peltzer from the Jet Propulsion Laboratory in Pasadena, Calif., have witnessed this type of continental escape before — in the laboratory, where they have used a type of modeling clay called plasticine to mimic some of the conditions of the Indian-Asian collision. The experiments, begun eight years ago, show that when a hard block pushes into the plasticine, cracks develop in the clay and force material to "escape" out of the way of the incoming block. As the original cracks warp, new cracks develop in front of the block and take the place of the old ones. Tapponnier and Peltzer say the plasticine experiments have bolstered the theory that continental escape dominates the way the crust deforms. Escape has absorbed 50 percent or more of India's collision with Asia, they suggest.

Other experiments over the last decade point in a different direction. England and Houseman have created mathematical versions of India and Asia to model the collision on computer. In their simulations, they see crustal thickening assuming the fundamental role in absorbing the crash of India. Escape of material to the east enters the drama only late in the final act, when the plateau starts to collapse under its own weight.

In the real-world example of Tibet, says England, crustal thickening probably represents almost all the deformation in Asia from the collision, with horizontal displacement accounting for "10 percent or less." He contends the eastward movement would have begun about 5 million years ago, when gravitational forces began to pull apart the Tibetan plateau.

In the early 1980s, the battle line formed between the crustal-thickening camp and the escape proponents, with each side rallying around its own experimental results (SN: 12/18&25/82, p.391).

Yet each of the physical and mathematical models has distinct limitations, says MIT geologist Clark Burchfiel. In the early plasticine experiments, a cover placed over the clay prevented it from expanding vertically. In a sense, he says, such experiments had to emphasize the importance of continental escape because the material could not deform by thickening. The numerical models, on the other hand, downplayed the role of escape because the continents in the mathematical collisions had boundaries on their edges that blocked sideways motion, Burchfiel says. Moreover, the simulated continents could not develop fractures that would allow blocks to slide eastward along faults.

Some researchers think the debate has created an unrealistic rift in the geoscience community, since the real-world continents must combine qualities of both experiments. "Unfortunately," says Houseman, "we ended up in a sort of polarized situation, which really was a bit unnecessary when you think about it." The escape vs. thickening debate has been "blown way out of proportion," partly because of the divergent experimental approaches used to study the collision, he contends.

But Molnar argues that the different experimental approaches really do reflect a deep and important division in thinking about the continents. During escape, the continents must break into *strong* blocks that slide past each other along *narrow* fault zones, whereas thickening requires that regions deform in a *weak* manner over a *broad,* diffuse zone, he suggests. Both processes take place to a certain extent, Molnar says, but learning which behavior dominates in various environments is important in tracing the history of the continents.

In the Tibet debate, the only fact that stands out is that there are too few facts. "The [theoretical] models have completely outstripped the data," says Burchfiel. "You can make a model a lot faster than you can get the data."

Adds Peltzer, "It's a part of the world where we don't have many data. It's not a complete unknown, but usually people try to say a little more than they actually can."

Part of the problem is political. Until 1979, when China first allowed official access to this long-forbidden region, Western geoscientists could study Tibet only through satellite images and bits of available information. Since then, the plateau itself has hindered study because of its vastness and the scarcity of roads.

Ongoing work may provide a clearer picture of the collision's history. Molnar, Burchfiel, Tapponnier and others are spending time this year studying different regions bordering Tibet. In particular, Tapponnier's work along the Red River fault should help reveal whether Indochina has undergone significant continental escape.

Information will come not only from classical geologic mapping of faults and mountains but also from space-age techniques. This summer, a team from MIT is attempting to use the satellite-based Global Positioning System to measure how crustal blocks currently move on the Tibetan plateau's eastern edge. Over a course of several years, the MIT researchers expect to learn whether south China is escaping toward the sea as Tibet slides to the east.

New data from the various studies may reveal that Asia has deformed through many different processes. Whether or not geoscientists embrace the escape theory, it's clear that continents do not follow the simple behavior patterns of the rigid oceanic plates. Says Tapponnier, who has just celebrated his tenth anniversary of field work in Asia, "The history of the collision between India and Asia is much richer and complex than we once thought." □