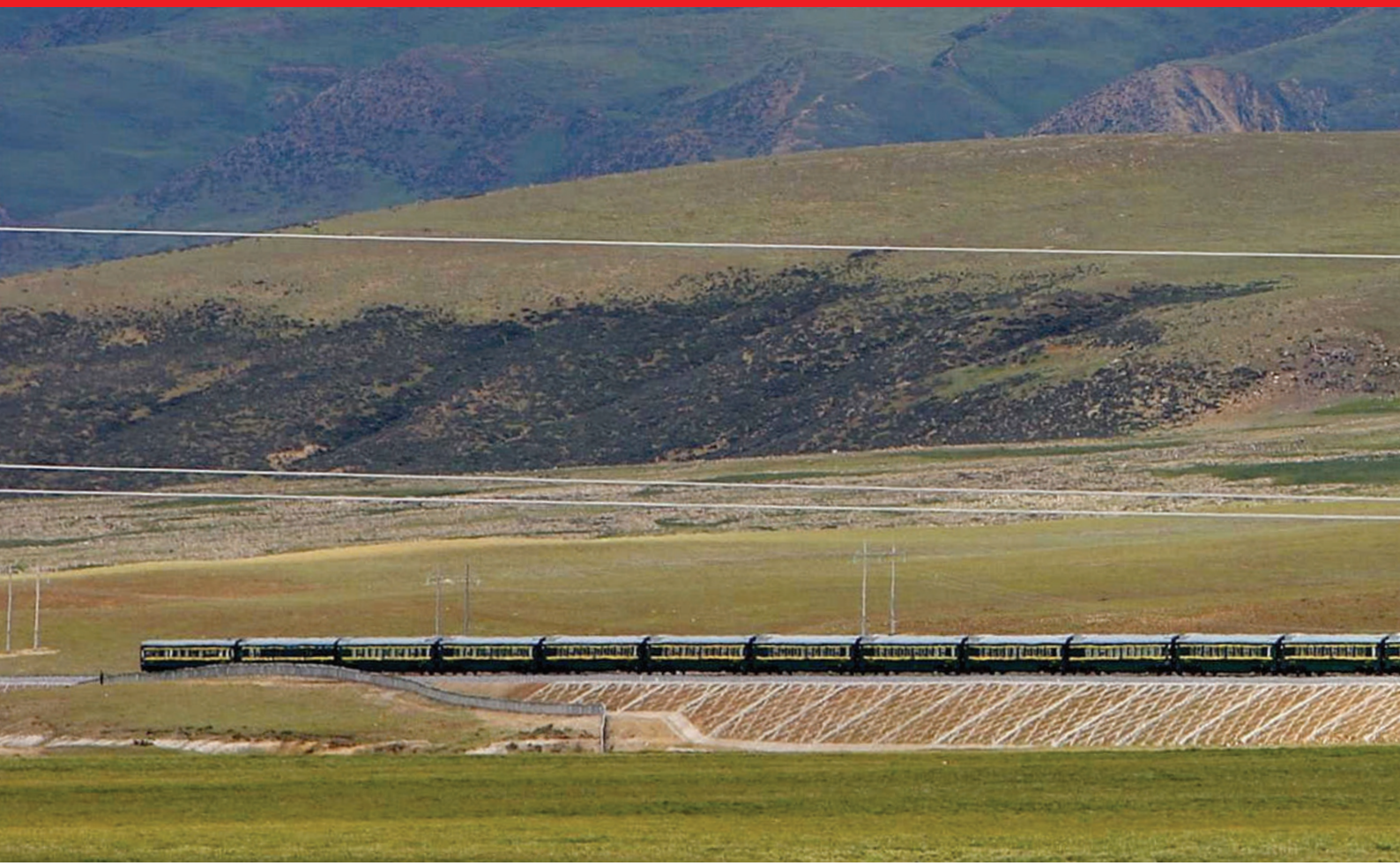


Riding on the roof of the world

China's railway to Tibet is an engineering marvel or an environmental menace — or perhaps both. **Jane Qiu** takes a ride to find out.

It is a glorious, crispy cold summer morning on the Qinghai–Tibet plateau, and already my lips are turning purple. At more than 4,500 metres above sea level, the air is thin and I can feel a light headache coming on. In front of me a pair of rail tracks stretch into the distance, looking as thin as silver threads as they negotiate a landscape filled by expansive glaciers and mountains with needle-sharp peaks.

The rattling sound of an approaching train jolts me to alertness and in no time it roars past us at 100 kilometres an hour, passengers waving gleefully from its windows. I'm painfully aware that the pressurized air behind those windows offers a great deal more oxygen than the stuff I'm breathing in the open air. "You will be fine," my Tibetan host, Tsega, pronounces after inspecting me up and down a few times. I feel obliged to trust his judgement.

The railway in front of me is the world's highest, and is a 1,142-kilometre stretch that connects Golmud, in China's Qinghai province, with Lhasa, capital of the Tibet Autonomous Region. It is also widely regarded as one of the great engineering achievements of the world. Its course crosses four mountain chains and five major rivers — with nearly all of it more than 4,000 metres above sea level. Successive Chinese governments, keen to tighten their grip on Tibet, have dreamed of such a railway for nearly half a century, and more than 20,000 workers laboured for 5 years to complete the project at a cost of 33 billion yuan (about US$4 billion).

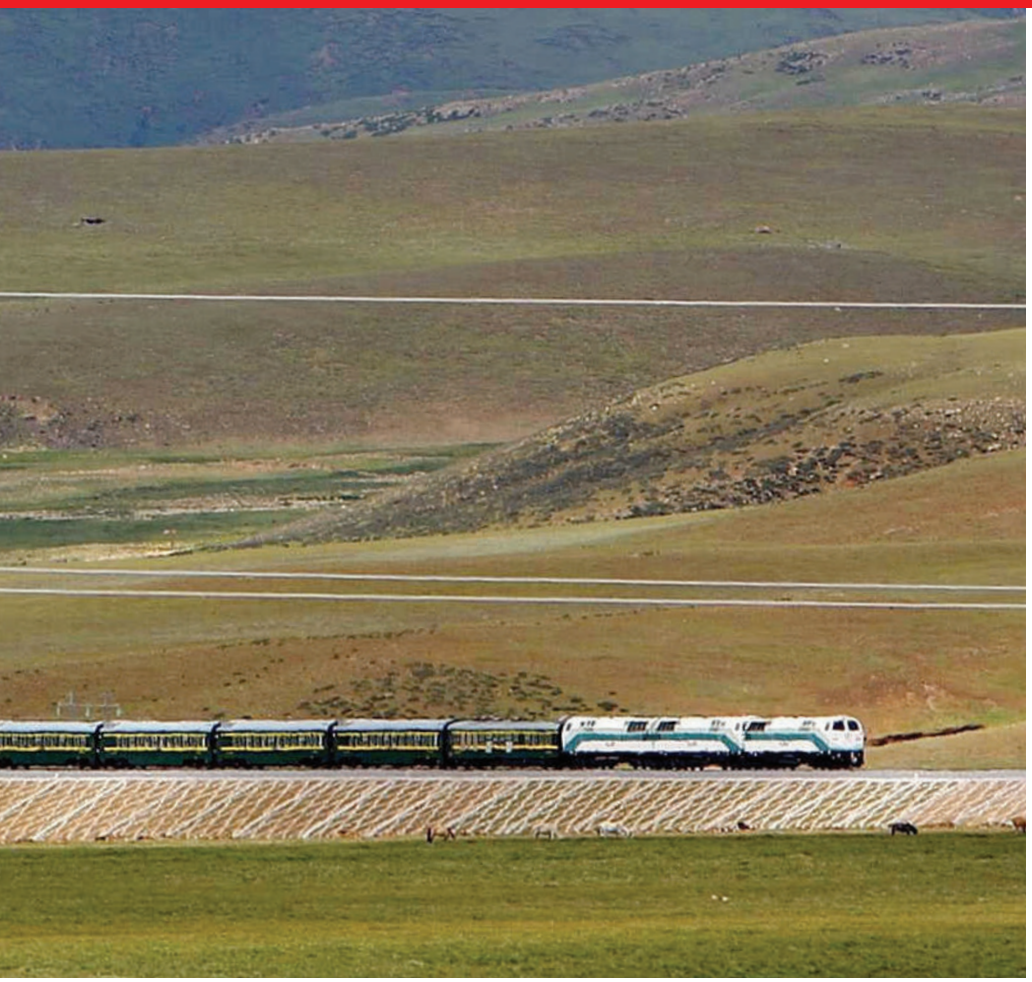
Now, more than a year after it opened, the railway remains a source of bitter controversy. Supporters say the scheme will bring major opportunities to China's underdeveloped west. Critics fear that China will use it to assert control over a contested border region, and to exploit its natural resources. The railway's long-term impacts on the plateau — direct and indirect — remain unknown, and I have embarked on a journey between Golmud and Lhasa — sometimes on the train, sometimes off it — to seek answers. The trip reveals how well the engineering is standing up after a year's worth of exposure to the harsh seasons; how the attempts to minimize its environmental effects have fared; and what the railway means to ordinary Tibetans.

> **"It would be very dangerous if passengers were exposed to the harsh conditions of the Qinghai–Tibet plateau."**
> — Wang Lanming

Earthquakes and permafrost

Tsega, who runs the Kekexili nature reserve from the office in Golmud, has kindly agreed to take me along on one of his regular surveillance trips to the reserve. After driving for 100 kilometres, we approach the gigantic Kunlun fault, a 430-kilometre surface rupture, ripped open by a magnitude-8.1 earthquake[1] on 14 November 2001. The scar from that quake is clearly visible in the landscape, and sends a shiver down my spine as we drive across it.

The earthquake didn't cause much damage to the railway because construction had just started, says Wang Lanming, director of the Lanzhou Institute of Seismology, China Earthquake Administration, in Gansu province. "But it was certainly a wake-up call for those of us involved in advising the engineers of the region's seismic activity," he adds. Two



SIPA/REX FEATURES

other quakes of magnitude 7.5 or greater have shaken the plateau in the past century, and seismic activity poses one of the major threats to the new railway.

The question is what to do about it. Railway engineers have avoided building stations, tunnels and bridges in areas containing active faults, and these main structures are equipped with anti-quake safety measures such as additional steel reinforcement bars to keep the concrete from cracking during an earthquake. But the tracks themselves do not have any extra reinforcement. "The cost would be astronomical to install anti-quake measures all through the route," says Wang.

However, researchers and engineers are in talks with the ministry of railways about installing an earthquake-detection system along the tracks on the plateau. The project, estimated to cost tens of millions of yuan, could, in theory, notify the train of a substantial earthquake in progress by detecting the primary seismic waves propagating from a quake, then bringing the train to a halt before the damaging secondary waves arrive. As Wang notes, stopping a train before it derails in a quake is particularly important for high-altitude railways: "It would be very dangerous if passengers were exposed to the harsh conditions of the Qinghai–Tibet plateau," he says.

The harsh weather here also calls for innovative approaches to railway engineering. As we crest the Kunlun Range, ahead of us we see how the rail tracks disappear into a 1.6-kilometre-long tunnel. "We are entering a region rich with warm permafrost," Tsega explains. The temperature of warm permafrost stays within a couple of degrees below freezing, and its top layer thaws more readily in the summer than that of normal permafrost, making the ground more unstable.

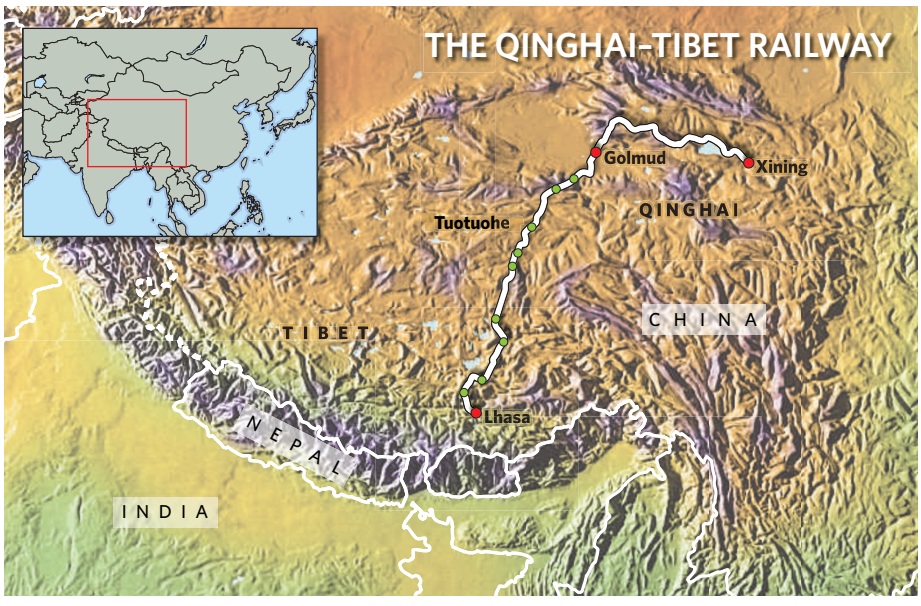
Regular permafrost is bad enough; engineers have to raise the railbed or use insulating materials to keep the tracks from warping during seasonal freeze–thaw cycles. Construction is even harder with the mix of permafrost types on the Qinghai–Tibet plateau. The railway traverses 275 kilometres of warm permafrost, 221 kilometres of ice-rich permafrost, and 134 kilometres of a mix of both. "This is the worst combination for any permafrost engineering project," says Max Brewer, a permafrost researcher at the University of Alaska in Fairbanks.

Keeping cool

A group of researchers, led by Cheng Guodong of the Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, in Lanzhou, has developed a series of measures to cool down the railbed. All the approaches capitalize on using the benefits of the cold environment, and try to keep the railbed as naturally cold as possible[2].

In most places, for instance, the railway embankment is raised by between 2 metres and 10 metres, helping insulate the ground from the heat created by the tracks. The slopes of the embankment are also covered with a layer of crushed rocks — a technique inspired by reports that permafrost can occur beneath blocky and coarse materials even when the air temperature is well above 0 °C. "This is the first time a large-scale project has used the technique as one of its primary solutions," says Zhang Tingjun, a permafrost researcher at the National Snow and Ice Data Center in Boulder, Colorado. It seems to be working; tests suggest that the crushed layer keeps temperatures up to 2 °C cooler, and in some places, the permafrost has even increased in volume and pushed up into the embankment structure.

As we drive along, passing Tibetan wild asses



Cooling pipes: ventilation ducts through the embankment keep the ground temperature up to 2 °C lower.

Q. YU

grazing by the road, I spot other gadgets along the tracks for cooling the embankment. The most prominent ones are 'thermosyphons' — a series of thin metal tubes standing upright on the railbed shoulders every 3 metres, which use evaporative cooling to transfer heat from one end to another. Thermosyphons are costly to install and maintain, but the Chinese government is not shy in lavishing on such gimmicks, with 18,200 of them installed in 'high-risk' permafrost areas.

Elsewhere, engineers buried ventilation pipes through the embankments, which can also cool the temperature by up to 2 °C. And some of the south-facing slopes hold giant shading-boards. Over the first winter, these allowed shaded areas to freeze solid while non-shaded embankments remained unfrozen.

More than 200 sensors constantly monitor ground temperatures on both sides of the railbed over permafrost regions, in a system costing 40 million yuan. One year and a seasonal cycle on, researchers suggest that the permafrost regions are recovering from the disturbance caused during the construction of the railway. But there have been several cracks along the track in some regions, which may be due to distorted foundations. Cracks are repaired as soon as they are discovered by the crew regularly monitoring the track. Zhang Luxin, chief engineer for construction and maintenance of the railway, would not disclose the total number of cracks since it began operating. But he says that all of the cracks so far have been superficial and have had no impact on the railbed.

Brewer says he is not alarmed by such incidents. "It would be naive to expect that construction of this scale could be free of problems," he says. Indeed, it has been more than a century since Siberia's first railway was built, but frost-damage still affects 30% of the tracks passing across permafrost regions, according to a recent survey conducted by Russian engineers.

Some experts, however, fear that the problems could get worse in a warmer climate. Research shows that global warming has affected the ground temperature on the plateau to a depth of 40 metres; permafrost is degrading as temperatures rise and the 'active' layer that freezes and thaws every year gets thicker[3]. According to a recent report by the Chinese Academy of Sciences, 10% of the permafrost regions on the plateau have degraded in the past 20 years.

> "It would be naive to expect that construction of this scale could be free of problems."
> — Max Brewer

Before 2001, when the railway constuction started, the consensus was that the air temperature on the plateau would increase by 1 °C over the next 50 years. Scientists now think that it may rise by 2.2–2.6 °C during that time. Cheng, however, says that engineers could adapt the railways to additional temperature increases by adding more of the cooling measures to the railbed's slopes.

Lack of oxygen sends excruciating pulses burrowing in through the top of my head and deep into my brain. I turn to the view outside, seeking comfort in the widening, sparsely vegetated valley, sprinkled with streams, rivers and enormous alluvial fans. In the distance, my gaze comes to rest on a gigantic overpass perching high above the plain. "That's the famous Qingshuihe Bridge," Tsega says, noticing my sudden enthusiasm. The 11.7-kilometre-long overpass, consisting of 1,367 piers and costing 24 million yuan to build, straddles the most unstable stretch of permafrost along the railway. The overpass removes direct contact between permafrost and the tracks — the engineers' last resort for protecting fragile ground.

Effect on migration

Tsega explains that the bridge is also one of 33 passageways designed to enable wildlife on the plateau to go under the arches to get from one side of the railway to the other. Chiru, endangered Tibetan antelopes known for their speed and stamina, are shy creatures and particularly prone to disturbances. Every June, more than 3,000 pregnant chiru travel hundreds of kilometres westward from the Three-River Headwater nature reserve to give birth in the Kekexili reserve, then migrate back with their young in August. Both the Qinghai–Tibet railway, and the highway that follows the same route, cut right across their migratory paths.

Experts are divided on the subject of how effective such wildlife passageways are. According to a government report released ahead of the first anniversary of the line's operation in July, most of the passageways are used by plateau animals and the railway has had no impact on the Tibetan antelopes in those areas. Other research is less positive. Contrary to reports by the state-run Chinese media, as many as 1,500 antelopes couldn't make the crossing in 2003 and had to give birth locally, says Yang Xin, president of Green River, a non-

G. ROWELL/MOUNTAIN LIGHT/ALAMY

The chiru is an endangered antelope found only on the Tibetan plateau.

R. JONES/REX FEATURES

Tang Gu La, at 5,068 metres above sea level, is the world's highest train station.

governmental organization based in Chengdu, Sichuan province. This happened despite the fact that railway workers suspended construction and cleared out of the sites for a couple of days during the animals' peak migration period.

Although antelopes are able to cross the railway, research by Yang and Su Jianping, a zoologist at the Northwest Institute of Plateau Biology, Chinese Academy of Sciences, in Xining, Qinghai province, suggests that antelopes don't use most of the passageways. Before the railway construction began, antelopes crossed the highway between the Kunlun Pass and Wudaoliang at multiple locations along a 100-kilometre stretch. Now, a large majority of them funnel under the 200-metre-long overpass at the Wubei Bridge, just north of Wudaoliang.

It's not yet clear what these changes in the animals' migration habits might mean in the long term. The researchers conjecture that some of the new overpasses might be too low or narrow for animals to feel comfortable, which pushes them into new migration routes. Yang, for instance, has seen herds of antelope approaching the Chumaer River — which used to be a key crossing site — then hesitate, turn away and go south to make the crossing near Wudaoliang.

Knowing why some overpasses seem to work better than others could be valuable for future construction work, says Su — but only long-term monitoring can find that out. "It would be surprising if the highway and railway didn't affect movements of plateau animals," he says. "It's unclear how this could affect their other behaviours or their survival as a species." Yang Qisen of the Beijing-based Institute of Zoology — leader of the team that studies the railway's impact on plateau wildlife — declined *Nature*'s request for an interview.

Throughout the journey, the plateau is otherwise little marred by construction debris or the landscape scars usually associated with major projects. Railway planners developed a 'green policy' to ensure protection for soil, vegetation, animals and water resources along the route[4]. Nearly 4% of the 33 billion yuan spent on construction was allocated to restoration of ecosystems and environmental protection, according to Hao Qingjun, an official at the Xining-based Qinghai Environmental Protection Agency. Where possible, the railway was rerouted around sensitive natural zones such as wetlands. In other places, much of the turf that was dug up during the construction phase was preserved and then replanted once that section of the railway was completed.

Accumulating rubbish

The sun has almost set by the time we pull off the road at the reserve's protection station near Tuotuohe for the last stop of the day. The lingering light sets the snow-capped mountain peaks ablaze, while long blue shadows creep down from their dark stony slopes.

Tuotuohe, a main town along the railway, lies in the region that is the headwater of three of Asia's largest rivers — the Yangtze, Yellow and Lancang (Mekong) rivers. Standing at the Tuotuohe Bridge, the first bridge over the Yangtze, I recall how Yang told me that the town is also the first rubbish dump along the river. The highway and railway are bringing more people and industrial products to the plateau. They have also led to more roads and other constructions, such as hotels and restaurants, along the route. "Those constructions do not have the same kind of resources as the railway project," says Yang, referring to the lack of money and manpower. "So environmental protection is not on the agenda."

Few towns along the route have the capacity to treat their accumulating rubbish, so it is left to moulder in open containers on the street and along the river banks. This is not only a source of disease, says Yang, but it also pollutes the environment and endangers wildlife. In addition, the introduction of commerce into the plateau life has led to an increasing need for more livestock, such as yaks, cows and sheep, which nomads can exchange for industrial products. "Over-grazing is a serious problem on the plateau," he says. In the Three-River Headwater region, some nomads have to go as high as 5,500 metres to find fresh pasture for their animals.

Change in Tibet

It soon turns pitch-dark and the temperature drops sharply. In the protection station we sit around a stove, enjoying the waves of warmth it radiates. A television is showing news on Phoenix TV, a popular Hong Kong channel. There is a computer in the corner with an internet connection. Tashi, a young Tibetan man who looks after the station, brings us supper: bread, yoghurt and Tibetan tea, along with some dried beef Tsega brought with us. Over the meal, I ask Tashi how the railway has affected his life and that of his family who are nomads in the region. "Our life is still the same," he says after a moment of hesitation, a sense of indifference palpable. None of his family or any of their friends sees a need for taking the train. "We are nomads."

> "Our life is still the same. We are nomads."
> — Tashi

His indifference, and that of many others living in rural Tibet, is in stark contrast to China's claimed purpose of the railway: to promote economic development. On the surface, Tibet is doing well, and the railway has certainly helped; during the first 10 months of its operation, trade between Tibet and outside regions increased by 75%, to 2.6 billion yuan. Tibet will receive an estimated 3 million tourists this year and, by 2010, the number is expected to reach 5 million.

Pleased with the railway? The reaction in Tibet to the railway project has been mixed.

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The billions of yuan that Beijing has poured into Tibet flow almost exclusively along the handful of roads in the region, pooling in the towns along the way and finally ending up in three major cities — Lhasa, Shigatse and Chamdo, says Kabir Heimsath, a Lhasa-based anthropologist at St Cross College, University of Oxford. The towns and cities are the few places in which serious development has taken hold and, consequently, are also the only places where Han migrants — mostly itinerant workers marginalized by the same system in other parts of China — and businessmen form a majority. This increasing disparity between the urban rich and the rural poor — a general problem of China's economic development — means that most Tibetans are left behind, unable to reap the benefits of modernization, he says.

GREEN RIVER

Untreated rubbish has accumulated in places along the Yangtze river.

Even in towns and cities, Tibetans are in danger of being marginalized. They find it increasingly difficult to compete in the job market against skilled and more business-oriented Han, who, privileged by ethnicity and language, make up more than 92% of the population of China. Intentionally or not, Tibet has seen a surge of Han migrants, which is further boosted by the railway. And emerging with this wave of migration is the cultural imprint of Han Chinese on many aspects of Tibetan life — even religion, as an increasing number of Tibetan monasteries are funded and built by Han Chinese.

On the train

A few days after visiting Tuotuohe, I board the train from Golmud to Lhasa for the uninterrupted experience of the entire train journey. The coaches are completely sealed so no rubbish can be thrown out and have a wastewater-storage system. They have windows with ultraviolet filters to keep out the sun's glare, and their underbellies are enclosed to protect wiring from snowstorms and sandstorms. The oxygen level in every coach is well-adjusted, and additionally, passengers can plug in to the oxygen supply anywhere on the train. Every coach is equipped with digital displays that show continuous updates of the train's elevation and speed, the outside temperature and the distance to the next station.

Travelling at about 100 kilometres an hour, the trip is surprisingly smooth. I have the opportunity to review the scenery — the magnificent Mount Yuzhu reaching up to 6,178 metres, the turquoise Namucuo Lake shimmering under the unearthly Tibetan light, nomads dressed in colourful robes, turrets with red, blue and green prayer flags fluttering near a Communist flag. Fourteen hours later, at the end of an uneventful journey, the train pulls into the great vault of Lhasa's new railway station.

The next morning I wander through the city's various districts. Apart from the Tibetan quarter centred on the holiest Jokang temple, most of the shops, hotels and restaurants are run by Han Chinese. I come across Bhuchu, a Tibetan pilgrim from a village in Sichuan province. He has prostrated himself on the ground after every step for more than 1,000 kilometres over the past 6 months. Now only steps away from Jokang, he is radiant with joy, hope and a deep sense of heightened existence.

I finally arrive at the Potala Palace, the historic landmark of Lhasa, which used to be home to successive Dalai Lamas. The sight of the gigantic red-and-white structure perching serenely on Potala Hill is simply breathtaking. Marvelling at its architectural splendour and spiritual richness, I can't help but wonder what the railway will bring to Tibet and its people.

Already, China is planning to extend the railway even farther, to Zhangmu to the west and to Dali to the east. Another extension would link Shigatse with Yadong, near the China–India border. What will this expanded network mean for the fragile plateau? Here in the rarefied environment of Lhasa, the question hangs shimmering in the air. ■

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1. Xu, X., Chen, W., Ma, W., Yu, G. & Chen, G. *Seismol. Res. Lett.* **73,** 884–892 (2002).
2. Cheng, G. Sun, Z. & Niu, F. *Cold Reg. Sci. Technol.*, doi:10.1016/j.coldregions.2007.02.006 (2007).
3. Cheng, G. & Wu, T. *J. Geophys. Res.* **112,** F02S03 (2007).
4. Peng, C. *et al. Science* **316,** 546–547 (2007).