Carleton Geology Department

Geology Comps Papers

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Desertification of the Gobi

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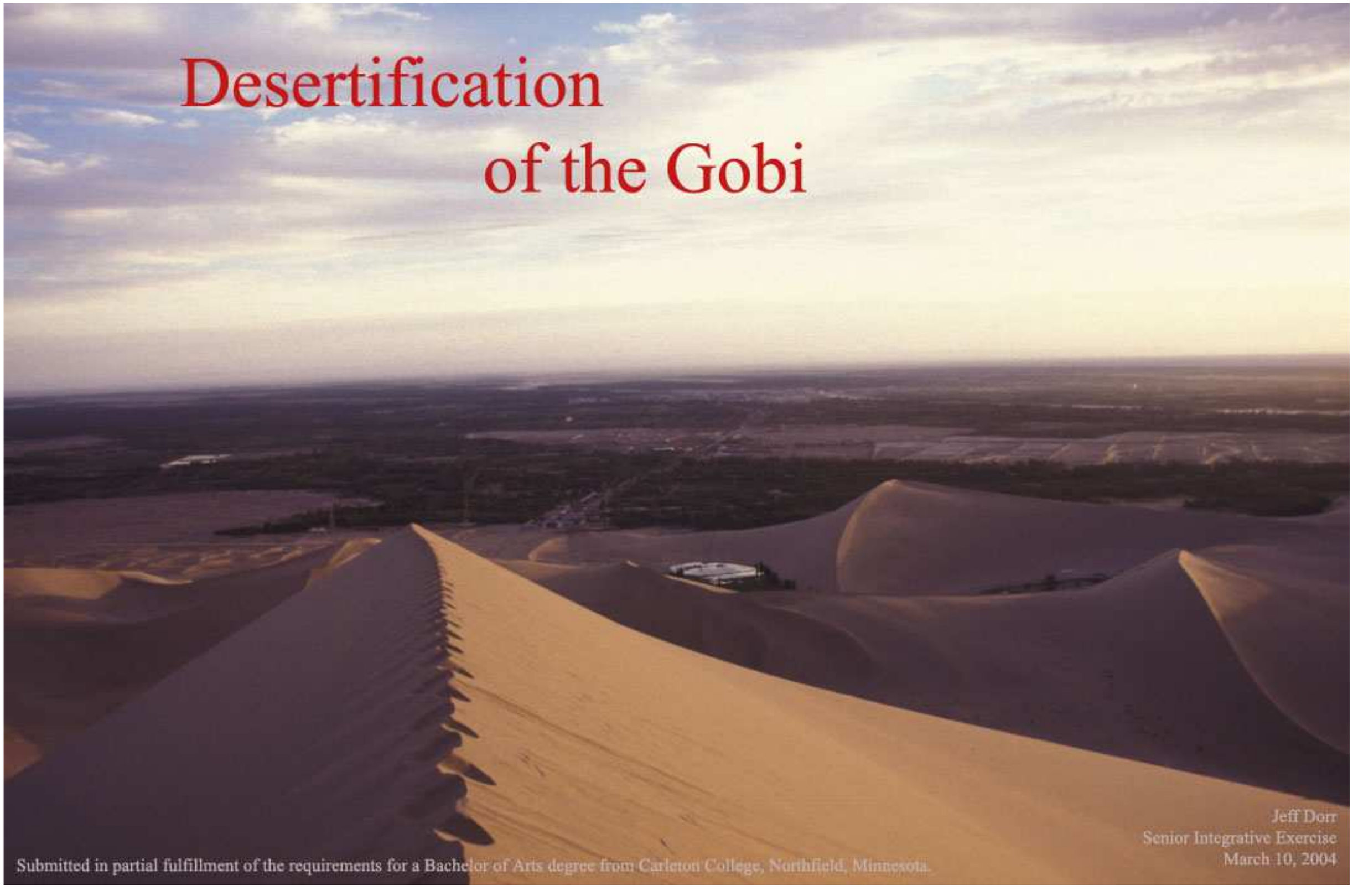

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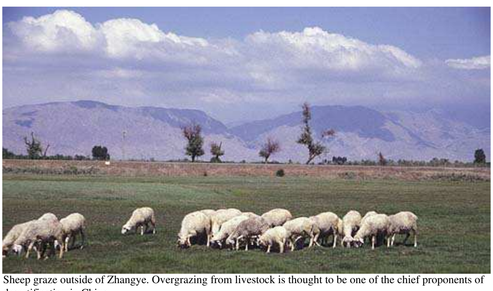
Foreword

China is a nation endowed with both an ancient civilization dating back over six millennia and a means for unprecedented economic growth in the 21st century. Having the single largest population of any nation on earth, China is currently the home of over 1.3 billion people. Since its inception to the World Trade Organization in 2001, China's eastern coast cities have discovered new levels of wealth and prosperity supported by the one of the largest and most rapidly developing economies in the world today. As a result, high-rise office buildings and apartments have sprung up on China's eastern seaboard, many of them half empty in anticipation of increased development in the immediate future.

Modern architecture lures scores of tourists to Shanghai's glitzy Pudong district.

In spite of recent developments, however, China's economy is still largely an agricultural one, and without arable farmland to feed its population, high-rise office buildings, modern industry, and international trade negotiations mean little. Efforts have been made by China's government to curb its population growth, but despite its implementation of a one-child policy in 1978, the average Chinese woman continues to bear two children.



Sheep graze outside of Zhangye. Overgrazing from livestock is thought to be one of the chief proponents of desertification in China.

For these reasons, agriculture is of vital importance to China's people and economy. Presently, however, much of China's western and northern lands are under threat of desertification, a process in which arable land is transformed into desert. Desertification is particularly dangerous for agriculture not only because it can transform productive cropland into desert, but also because the desertified land it creates contributes to increased erosion, stronger winds, and fiercer sandstorms. The process of desertification can result for a number of reasons, but most scientists agree that overpopulation, combined with inefficient farming techniques and an ecosystem already strained for water are undeniable factors behind China's current crisis.

As a result, the deserts of China are currently expanding. Estimates predict that around 950 square miles of land become desertified on a yearly basis. Additionary, losses to China's agricultural output cost the nation an estimated 6.7 billion dollars per year in land degradation, telecommunications maintenance, and transportation costs. Encroaching sands pose a variety of challenges on the traditional lifestyles for millions of Chinese as the desert's steady growth forces them to cope with increasingly violent sand storms and nutrient-deplete soils on their croplands. In response to the Gobi's expansion, China has proposed a diverse number of solutions to prevent further land degradation ranging from miniature ecosystems of vegetation uniquely suited for desert conditions to petroleum-based sprays that halt advancing sands.

At China's current rate of desertification, even fertile lands such as these in Xiahe, Gansu, could conceivably be endangered within the next three decades.

Despite the Gobi's importance to millions of Chinese, few westerners are aware of the region's significance as one of the most challenging environmental problems faced by modern society. Based on the results of a two month voyage through China's Hexi corridor in July and August of 2002, the contents of this web page are intended to describe a modern struggle between man and a geological process, as well as inform readers about some of the Gobi's most striking geology. The photographs and information included are intended to promote awareness about the challenges China faces as a result of desertification and to communicate the impacts of this geological process on millions of farmers and herdsman living there today.

-Deserts of China-

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Deserts of China

Though not a nation well renowned for its arid regions, China's 12 deserts occupy 1.49 million km2 of its terrain and constitute 15.5% of the nation's total surface area. In order of decreasing size, these deserts include the Taklimakan, Gurban Tunggut, Badain Jaran, Tengger, Mu Us, Kumtag, Kerqin, Otindag, Kubqi, Ulan Buh, Qaidam, and Hulunbeir deserts. How did these deserts form? If one observes the prevailing weather patterns over the Asian continent, China's northern and western provinces derive most of their weather systems from bodies of air making their way over the Himalaya from India. Scientists believe that the formation of the Himalayan Mountains, which reached their current height some 22 million years ago, have played a significant role creating these deserts by robbing winds and monsoons from India of their moisture before they reach northern China. This phenomenon occurs because water suspended in air naturally condenses into precipitation at higher elevations. Thus, any air that pushes over the Himalaya from India becomes exceedingly dry by the time it reaches China. For this reason, deserts that form behind mountain ranges are sometimes known as 'rain shadow deserts.' In a sense then, China's arid regions are generally regarded as rain shadow deserts, owing their existence to the immensity of the Himalayan Mountains and the Tibetan plateau.

Numbers corresopond to deserts, letters depict cities. The gray region north of the Qilian mountains represents the Hexi Corridor, the region of focus in this site. (Modified from Fullen, 1994)

Mountains outside of Golmud on the Tibetan plateau.

The author stands surrounded by a gobi plain outside of Dunhuang.

Although the word 'desert' may conjure images of rolling dune fields, roughly 42% of China's desert surface area is Gobi, and only 58% sandy desert. In Chinese, gobi literally means "gravel expanse," and that is exactly what this type of desert looks like. Usually flat, bare, and partially vegetated, gobi forms when strong winds pick up fine sediment from dry lake beds, rivers, or loose soil and deposit it somewhere else. As a result, coarse sediment, gravel, and rock are left behind, forming gravel plains. Geologists refer to this removal and winnowing of fine sediment by wind erosion as deflation.

Sand sea of the Mingshashan dunes.

Conversely, areas in which winds lose speed and deposit these fine sediments become dunes fields, forming landscapes which are more typically associated with desert topography. In scientific literature, dune fields are also described as sand seas or sandy lands. In contrast to rolling dune fields then, the deserts of China are a rich tapestry comprised of wind cut expanses of gravel desert cut by swaths of undulating sand seas.

-What is Desertification-

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What is Desertification?

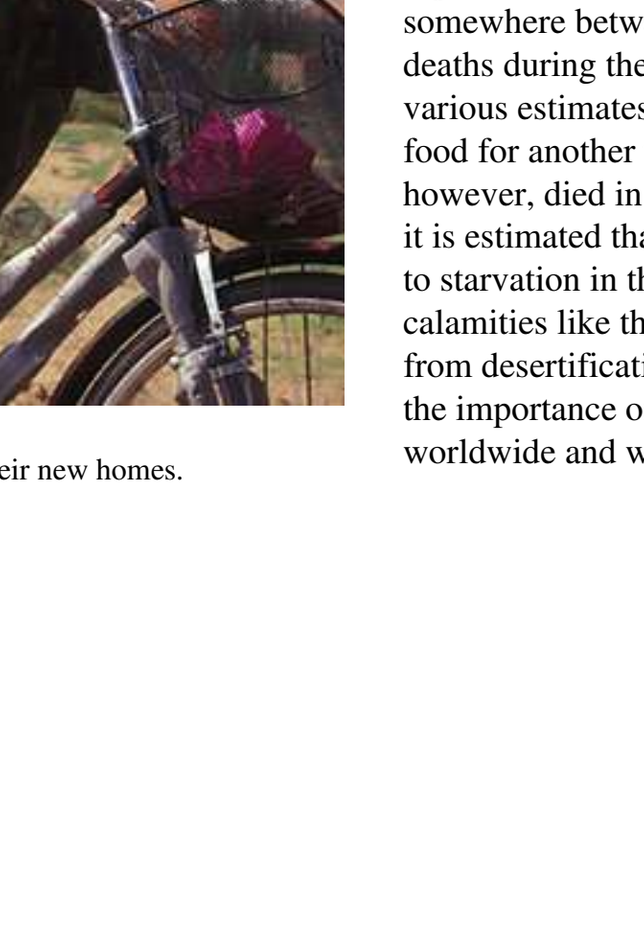
Desertification describes a process which reduces the potential fertility and productivity of land to the point where its biological ecosystems, plants and animals alike, degrade or die out altogether, resulting in an environment of desert-like conditions. Though desertification is sometimes associated with 'desert creep' or 'encroaching sands,' naturally advancing sands due to drought only represent roughly 5-8% of desertification worldwide. The other 92-95% is a man-induced process. Most media coverage of desertification tends to focus on large sandstorm events which bury homes and roads, but at the heart of the issue, desertification results from humans trying to extract resources from ecosystems already strained for water and stability. Unfortunately, the additional pressures of human disturbance all too often prove impossible for natural ecosystems to endure, leading to their destruction and ensuing desertification.

Drifting sand blows over a highway in the Tenger desert. Every year, accidents occur along roads like these due to drifting sand.

Worldwide, desertification is an issue on every continent outside of the polar caps. Founded in 1994, the United Nations Convention to Combat Desertification (UNCCD) estimated in 2000 that somewhere between $10-22 billion would be needed annually over a 20 year period to effectively combat desertification worldwide. The three regions addressed at the forefront of this campaign included Africa, Asia, and Latin America and the Caribbean, in descending order of importance. In Africa, roughly ¾ of drylands have already experienced desertification, and the continent's frequent draught and dependence on its own natural resources for food make it particularly susceptible to the dangers of desertification. Indeed, in the African Sahel region, desertification was responsible for somewhere between 50,000-250,000 human deaths during the early 1970's, depending on various estimates, and the call for emergency food for another three million. Animals, however, died in the millions. During 1972 alone it is estimated that 3.5 million cattle perished due to starvation in the Sahel. Although mass calamities like these have never since resulted from desertification, these events all demonstrate the importance of recognizing desertification worldwide and working toward its prevention.

Relocated farmers in Hongsibao, Ningxia have found an easier life in their new homes.

In Asia, desertification threatens lands in China, India, Iran, Pakistan, Laos, Mongolia, Syria, and Nepal. Though lands in these nations have not undergone desertification on the same scale as Africa, land degradation here influences the lives of more people on this continent than any other. Likewise, desertification has also been identified as a significant problem in Latin America and the Caribbean. Though these areas are better known for their tropical forests, ¼ of their total land areas are covered by dry lands that are currently at risk by economic development combined with the region's high rate of poverty. In terms of the number of people affected and land area endangered, however, no single nation has been impacted by desertification as much as China, where the lives of roughly 400 million people and 3.3 million km2 of land are threatened by this environmental process. Largely as a result of desertification, China is also now the second largest producer of atmospheric dust in the world.



-What Causes Desertification?-

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What Causes Desertification?

Although at a regional level some localities in northern China have experienced increasing draught in recent years, scientists have been unable to find a statistical relationship between increased aridity, land degradation, and the increased frequency of dust storms. This evidence has led experts to the conclusion that desertification is largely a man induced phenomenon. Most authorities agree the principle factor behind desertification has been the urbanization of rural resources in China's recent past, and the ensuing deforestation, overcultivation, overgrazing, and mismanagement of water resources that has occurred as a consequence.

Open-air channels used to distribute water throughout the Hexi corridor are subject to rapid evaporation, day in and day out.

As populations consistently grow and modernize in northern China, an increased number of people seek to make a living within cities. This trend in urbanization has contributed to the centralization of human populations in specific localities, adding to the pressures of human demand on the natural ecosystem. In many cases, regional ecosystems already strained by draught fail to meet these demands, resulting in land degradation and desertification. Of these demands that humans place on their environment, deforestation is thought to be among the chief causes of desertification. In addition to land clearing for agricultural, industrial, and construction purposes, 90% of all energy use in rural China is dependent on firewood and charcoal. In many regions, firewood has become so scarce that people have resorted to cutting living wood from trees. As a result of deforestation, natural soils and plants that have been naturally shaded and protected by trees for thousands of years have suddenly been exposed to levels of heat, sunlight, wind outside of their living threshold, resulting in their death. Without trees or vegetation holding soils in place, rapid wind and water erosion carry valuable nutrients away, depleting soil fertility and causing desertification.

Cranes in Jiayuguan mark the rapid growth of the city, despite its problems with desertification.

Overgrazing of grassland and other forms of natural vegetation is widely considered an important cause of desertification.

Like deforestation, overgrazing is another leading cause of desertification. Though feeding on vegetation certainly contributes to the problem, livestock also compact the soil they walk on, thereby limiting its ability to absorb precipitation and disturbing vegetation and root systems in the process. As a result of grazing and trampling, vegetation systems that hold soils together die out, leading to erosion and desertification.

Another primary source of land degradation originates from overcultivation. In short, farmers unfamiliar with traditional dry land farming fail to rotate their crops on a frequent basis and attempt to extract harvests from their fields too often. Consequently, soils grow increasingly deplete in nutrients and less productive until farmers abandon planting them altogether, allowing for their rapid desertification. Finally, many farmers in northern China mismanage their water resources, inadvertently causing further land degradation. In particular, irrigation ditches are a leading source of desertification, as farmers frequently use them to flood their fields too quickly for plants to absorb the water. As a result, high rates of evaporation concentrate salts and alkalines in the water and soils, decreasing plant productivity. Furthermore, some plants and seeds become so waterlogged during the process that their root systems are weakened, resulting in potential crop loss. Though irrigation is generally better than none at all, field flooding remains an outdated technique used extensively throughout northern China and is thought to dramatically reduce crop yields from their potential. Due principally to these factors of deforestation, overgrazing, overcultivation, and mismanagement of water resources, China's desertified land surface reached an estimated total of 370,000 km2 in 2002, and at that time was growing at a rate of over 1000 km2 on an annual basis. Furthermore, despite China's afforestation plans to halt desertification, successful tree planting has only reclaimed an average 200 km2 worth of desertified land per year since the 1980's.

When managed properly irrigation canals can lead to productive crop yields. Often, however, fields are flooded too high too quickly, resulting in concentrated alkalines and salts in the soil.

-Hong Kong to Xi'an-

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Hong Kong to Xi'an

Hong Kong's Victoria Harbor.

Flying over China at twenty thousand feet, Hong Kong's city lights provide my first glimpse of this bustling metropolis. Reacquired from a century of British rule in 1997, Hong Kong's outward appearance gives no indication of its economy slowing down.

Glistening skyscrapers and high-rise apartment complexes continue construction at a brisk pace, and streets in the city's downtown shopping district are just as alive and crowded as they ever have been. For me, however, Hong Kong is but a brief stop on a larger journey to China's northern deserts and sandy lands.

Xi'an's modern skyline.

A thirty-odd-hour train ride takes me from Hong Kong to Xi'an, a city held as a capitol of ancient China for twelve dynasties. Xi'an, once called Chang'an for nearly three millennia of its existence, is a city teeming with history. Its fourteen kilometer city wall, originally built in 1370, still stands today. Compared to Hong Kong, the pace of life in Xi'an is far more subdued, but a relatively modern skyline still stands, and an unmistakable foreign presence crowds its downtown streets, mainly due to the city's international fame as home to the Terracotta Soldiers.

-Zhangye-

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Zhangye

Twenty hours by train, followed by ten hours on wildly bouncing bus brings me from Xi'an to the city of Zhangye. Located in the Hexi corridor, a narrow strip of fertile land sandwiched between the Qilian Mountains and the Badain Jaran desert, Zhangye was once a resting stop and important trading post along China's ancient Silk Road. Zhangye sits in a lush oasis, and although the inner city and its immediate surroundings are rich with water and good land, the city is surrounded by a vast expanse of gravel desert. Arriving in Zhangye, one can easily discern a stark change from the bustling, busy streets of Xi'an to a peaceful calm.

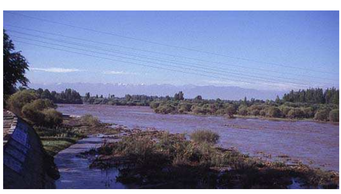
A new day begins in Zhangye's central square with morning excercises.

Outside of Zhangye's city center are the farmlands that sustain the city. The most popular crops here are corn, wheat, and sunflowers. It is here that I meet an elderly woman who has been farming in Zhangye all her life. Like many of the farmers that live in this region, she lives in a mud-brick home with her family. Behind her home is a small pen where she and her family keep two cows, sheep, and a small host of chickens. Further back still are plots of corn and wheat neatly divided into mu, a unit of measurement roughly the size of one sixth of an acre.

As operator of his village's electric pump, this man plays an important role in his community. Over half of the Hei He's river is now diverted to Inner Mongolia, and pump operators like him have an obligation to make sure that water consumption is strictly enforced.

July and August are the rainy season here, but when annual rainfall averages only 3.6 inches per year, farmers need to rely on other sources for water. Fortunately, the oasis of Zhangye has a wealth of water available owing to the Hei He, or Black River, which descends from the Qilian Mountains to Zhangye's south. When the fields surrounding her home demand irrigation, locals use a newly installed electric pump to carry water from a pipe that runs directly to the Hei He. In this way, fields here are irrigated roughly twice a month during the growing season, depending on rainfall.

Today the Hei He, pictured at right with its source in the glaciers of the Qilian Mountains, is the lifeblood of Zhangye. Without it, farmers would have no water for their crops, and the city would simply wither into the sands of the surrounding desert. In ancient times, however, the Hei He used to flow northward into Inner Mongolia, finally channeling itself into the Gaxun and Sogo lakes. Though Sogo Lake still has some water remaining in it, Gaxun dried up entirely by 1961, leaving a flat, desiccated bed, or playa in its place. Recent studies have shown that around 3000 years ago, these lakes converged with one another and may have covered an area over 800 km2. Today's maps depict the once mighty Heihe as a dashed blue line straggling into Inner Mongolia - a tribute to its memory in Chinese civilization.



Further from the center of Zhangye, the lush oasis begins to change to dryer, harsher landscape. Here in the far reaches of the city, desertification is a constant threat to farmers as sandstorms from the surrounding desert can easily blow onto their lands, covering their crops in a layer of sediment that can ruin the harvest. To help combat the process, the Chinese government and city council have mandated that farmers plant trees. Every March, every farming village in Zhangye divides itself into fifteen teams, each of which consists of approximately fifty families. Each team then has a specific quota of trees that it must plant in a particular area, which it must meet or face a fee. Such revenues collected by state officials are spent hiring alternative labor to plant trees wherever they are most needed. Despite the arid conditions and poor quality of the soil, much of these efforts have succeeded in stabilizing soil that might otherwise readily turned to desert.

Improved methodology and the use of new species of plants have dramatically reduced the time necessary for farmers to convert desertified land into arable soil. What used to take farmers eight to ten years to make soil arable for planting can be done in merely two or three. Rows of red willow trees, planted perhaps thirty years ago to fix sands here, stand in middday sun as testament to man's ability to occasionally control desertification.

A kilometer or two outside of Zhangye, a man sits under the shade of an umbrella and a brick hut at his outpost along a deserted highway. Surrounding him is gobi, an expanse of gravel and sand interspersed with shrubbery, but behind him sit several plots of neatly planted greenery - trees, shrubs, and other grasses that government has placed here to test in desert conditions. Plants that are able to survive in these conditions, he says, will probably be used for fixing sands in Zhangye and other regions facing problems with desertification. Zhangye's government also intends to plant the most stalwart specimens beside desert highways and roads in order to help prevent blowing sand from covering roads and reducing visibility for drivers.

Altogether there are ten different types of trees planted here, as well as a smaller assortment of grasses and shrubs. The man's job at this lonely outpost is a monotonous one - he stands watch for rabbits and other desert rodents that threaten to eat the bark and leaves of the newly planted saplings.

Dead trees line a roadside ditch outside of Zhangye, evidence of a failed experiment.

-Jiayuguan-

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Jiayuguan

Six hours of a bone jarring bus ride through a seemingly endless gravel desert takes me west of Zhangye to the city of Jiayuguan. Famous for holding the end of China's 2000 km Great Wall, Jiayuguan is yet another oasis city surrounded by an endless expanse of Gobi. Slightly larger than Zhangye, Jiayuguan has a similar slow pace of desert city life as its eastern neighbor.

Bicycles line stores along one of Jiayuguan's main city streets.

A journey to a desolate farming community on the outskirts of the city traverses several kilometers of desert scenery typical of that found surrounding Jiayuguan. On the way a dry riverbed, perhaps thirty meters wide, stands testament to the melting glaciers of the neighboring Qilian Mountains. In early spring, such glaciers send torrents of water toward the city, eroding wide channels like this one in their wake.

An irrigation channel disappearing into the horizon provides a means for farmers living outside the city center to obtain water when precipitation becomes scarce.

Nearly five kilometers out from the city center lies the hinterland that separates the Jiayuguan oasis from desert. Here, a sixty three year old man who calls himself Ma Daode stands by a small pond while his sheep graze lazily on grasses and reeds by the water's edge. Ma Daode remembers that at the age of twenty, this very same pond used to rise up to his chin. Now, he says, they only reach his waist. According to Ma Daode, farmers in his village worry a great deal about sandstorms that seem to grow in number and strength with each passing year. Every spring farmers plant red willow trees and Xinjiang poplars to help prevent further desertification. Red willows, he says, are well suited for fixing sand, while poplars, planted in tightly packed rows around plots of land, effectively shield crops against strong winds carrying drifting sands. Pointing toward an outcrop of low-lying dunes in the distance, Ma Daode says that ten years ago such sandbanks used to be much further away, perhaps as far as one kilometer out from their present resting place. With their increased proximity, sandstorms in his village have grown worse every year, and given sufficient time, farmers are concerned that the dunes will bury their homes and croplands altogether.

To slow the process, farmers in Jiayuguan have attempted planting trees and grasses directly in the path of migrating sand dunes in the hopes of protecting their land. Bidding farewell to Ma Daode, I make my way toward a nearby dune field where he tells me some trees have been recently planted. Depicted at right, evaporates fill ruts and ditches along the road that leads from Ma Daode's village out towards a nearby dune field. Salt deposits like these are common in arid environments where evaporation outpaces rainfall, leaving alkaline and halide crusts behind where water once stood.

Just short of the dune field, a miniature ecosystem of freshly planted greenery suddenly springs from the earth. Here, farmers have planted saplings in the hopes of stabilizing the soil and hindering the advance of the dunes toward their croplands. Though the sand hills still appear somewhat distant from this patch of greenery, a brief glance at an area closer to the dune field immediately validates the concern of the farmers. Closer to the dunes, blowing sands have already begun to encroach over newly planted saplings, slowly burying them in their wake. Despite these threats, however, Jiayuguan still attracts an abundance of immigrant farming families that move here annually from Ningxia, Gansu's eastern neighboring province. Farmers in Jiayuguan have their worries, but as long as a living can be made, they are still better off than many in other parts of the country.

Sands carried by wind from neighboring dunes begin to advance on vegetation planted to stop their progression.

Turning back toward Jiayuguan, one can discern the city from the perspective of the dunes. Here, the Jiayuguan oasis is depicted by a wall of poplars constructed as a barricade against invading sands. The 5000+ meter peaks of the Qilian mountains, shown in the background, support much of Jiayuguan's agriculture through glacial melt.

Left: The author stands in front of the famous July 1st Glacier in the Qilian Mountains, 120 km south of Jiayuguan. Ice walls of this glacier frequently reach 65 meters in height.

-Dunhuang-

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Dunhuang

The ride west to Dunhuang proved an even bleaker landscape in the absence of the Qilian mountains than previously experienced on the road to Zhangye and Jiayuguan. A temporary breakdown afforded an opportunity to capture an expanse of gobi outside of the minibus in the heat of the afternoon sun. The sight of Dunhuang itself, however, is a relief to the eye, a striking swatch of green set against a backdrop of the brown sands of gobi.

A strip of gobi between Jiayuguan and Dunhuang.

In ancient times, Dunhuang served as a critical trading post along the Silk Road. Today the city draws tourists who flock to see its dunes and cave paintings at the famous Mogao grottoes. Though the atmosphere of the city center caters to tourism, the periphery of the oasis is much like Jiayuguan and Zhangye. Here, in addition to corn and wheat, farmers also grow cotton and Hami melons. On the outskirts of the city, a man named Song Zhengfu and his wife Wang Xiuying, who preferred not to be photographed, demonstrate a technique locals have adapted for ensuring maximum moisture retention in their soil. Rather than simply planting seeds and leaving their crop soil exposed to the elements, Song Zhengfu and his wife first take care to prepare their land for planting by digging shallow trenches in neat rows across their land, and then covering their earth with a thin layer of plastic. Afterwords, seeds are planted on the mounds by cutting small holes in the overlying plastic and burying them under the earth of the mounds. Finally, holes are cut in the plastic overlying trenches to allow irrigation water to reach the roots. The plastic, explains Song Zhengfu, retains moisture in the soil, while the trenches help conduct precipitation and irrigation directly to the roots of the plants.

Without regular water, fields rapidly turn to hard, alkaline encrusted pavement. Farmers on the outskirts of Dunhuang claim that desertified land usually takes two to three years of "washing" with fresh water before crops can be planted in soils like these.

Close up of evaporites on an unused plot of land. Lens cap here is for scale.

Bicyclists peddle across a bridge over Dunhuang's Dang River, which flows north from the Qilian Mountains. In late July, the Dang river is already mostly dry, its springtime floods already complete.

Song Zhengfu and his wife depend on water from the Dang river for water, a body which flows from the Qilian mountains into Dunhuang. Irrigation channels carry water from the Dang river to his land, where he uses it to flood his land. When water levels are low, as they often are outside of springtime, Song Zhengfu says that he depends on a communal well nearly ten meters deep to keep his crops alive.

Song Zhengfu estimates that during late winter and early spring, he faces about four sandstorms every month. Small ones last only ten or twelve minutes, but large storms can last an entire day. Often, he says, a few centimeters of dust cover his plants, which he must broom to keep them alive. In 1996, Song Zhengfu remembers one large storm that completely submerged a field. He had no choice that year but to give that crop up. Sometimes, he says, new farmland gets converted back into wasteland, despite his efforts and those of his village. And sandstorms here have been getting worse as far as he can remember.

While many farmers struggle to make a living in the face of desertification, some have learned to embrace the process altogether. China's Badain Jaran desert, which roughly covers 49,000 km2 of land houses the largest dunes on earth, the highest of which stand over 450 meters tall. Though not the dunes of the Badain Jaran, the sand mountains surrounding Dunhuang are large enough to remind one of their proximity, and have consequently become a major tourist attraction, drawing hoards of Chinese and international tourists alike to catch a glimpse of their majesty.

The road to Dunhuang's famous Mingshashan, or singing sand dunes, is decorated by a string of colorful umbrellas, under which vendors sell trinkets and memorabilia to passing tourists. Beyond the vendors, the entrance to the dunes is marked by a multitude of camels, each of them harnessed to carry visitors up into the surrounding hills for toboggan sledding, paragliding, and a host of other activities. Though most visitors are unaware, the unique pyramid-like shape of these dunes and their size are the result of the unique environment in which they have grown.

Bactrian camels like these wait to carry tourists up into Dunhuang's Mingshashan.

-Dune Morphology-

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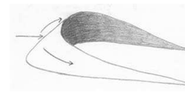
Dune Morphology

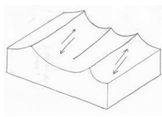
Dune shapes and sizes are primarily determined by the wind patterns of the region in which they form. Although their exact classification is an issue that continues to be debated between scientists, most agree that three are three major types which constitute most sand seas.

Crescentic dunes in the Tenger desert.

Dunes that form in regions where prevailing winds consistently blow in a single direction are known as crescentic, barchan, or transverse dunes. Such dunes are the most common form found worldwide, and can be identified by their crescent-shaped form and two trailing "horns" that extend downwind from the tips of their curved ridgelines. Where sand availability is scarce, isolated dunes will form, but in regions of high sand supply, the dunes will merge together to form a string of crescentic ridgelines. The largest crescentic dunes on earth are in China's Taklimakan Desert and stand over three kilometers wide.



Schematic depiction of a crescentic dune, with two trailing horns. Arrows represent wind direction and air flow around the dune structure.



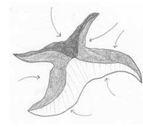
Linear dunes and their wind regime. In contrast to crescentic dunes, linear dunes form parallel to the bimodal winds that form them.

Unlike crescentic dunes, ridgelines of linear dunes are characteristically long, straight, and continuous. Although their formation is poorly understood, these dunes usually form in regions with bimodal winds, where two prevailing wind directions directly oppose one another. These dunes have ridgelines that extend parallel to the winds that form them and can extend up to 160 km in length.

Star dunes like those found near Dunhuang are the typically largest form, both with respect to their height and sand volume. Such dunes grow in a pyramid-like shape, and have at three or more arms that radiate outward from a central peak. Most star dunes are gently sloped at their base, but grow progressively steep near their peaks. The unique shape of these dunes is attributed to the multidirectional wind regimes in which they grow. Multidirectional wind patterns are brought about both by seasonal variation and by mountains and other topography impeding traditional winds regimes, resulting in complex interference patterns that frequently change in direction and strength.

A pyramid-shaped star dune towers over poplars planted to halt its advancement at Dunhuang's Minshashan.

As a result of the wind regimes in which they grow, star dunes experience more upward growth than other dune forms. The tallest star dunes on earth can be found in China's Badain Jaran desert and stand up to 460 meters tall.



Left: Aerial view of a star dune and its complex wind regime. Although a host of wind directions are drawn, only one of these winds will dominate the formation of the dune at any given time. Wind regimes typically vary on a seasonal basis.

In most cases, star, linear, and crescentic dunes grow individually, and are thus classified as simple dunes. A large dune, however, may also have multiple dunes of the same form superimposed on itself. To distinguish this characteristic, these dunes are referred to as compound dunes.

Compound dunes in the Badain Jaran. (Yang, 2004. Used with permission of the author)

Conversely, some large dunes are comprised of two or more different forms superimposed on top of one another. To geologists, these structures are known as complex dunes. Although it might seem that each of these dune types would form independently from one another in association with their specific wind environments, complex dunes are relatively common in nature.

Ripples superimpose themselves on a crescentic dune in Dunhuang's sand sea. This crescentic dune is situated on the face of a larger star dune, forming a complex dune structure.

In Dunhuang's Mingshashan, Chinese scientists have deduced that its pyramid-shaped dunes are the result of the sand sea's unique location near the center of the Asian continent and the prevailing wind patterns that emerge there. During winter, scientits have determined that dense, cold air centered over Mongolia results in winds that generally trend southeast across the Tarim basin and through the Hexi corridor over Dunhuang. In summer, however, these winds shift as monsoons over India push northward, driving winter winds north of Dunhuang. In the presence of this warm, buoyant air, the winds over Dunhuang change, resulting in currents that trend southwest.

A ridgeline of one of Dunhuang's larger star dunes curves upward to its peak.

The Mingshashan sand sea.

Data collected directly on the surface of the dunes surrounding Dunhuang, however, indicate that sand is primarily blown from winds that trend northeast, and to a lesser degree, winds from the southwest, northeast and northwest. But giiven the southwesterly and southeastern winds that dominate the upper atmosphere over Dunhuang, how could this be? Recently, scientists have answered this question by attributed the phenomenon to Dunhuang's proximity to the Qilian Mountain Range, which at 5000+ meters stand both tall and broad enough to impact the wind regimes that blow locally over Dunhuang's Mingshashan. Researches believe that the magnificent pyramid-shaped dunes around Dunhuang owe both their unique shape and size to these winds, each of which varies in strength with seasonal change. Attempts at simulating these conditions in laboratories have proven successful in growing pyramid shaped dunes, supporting their hypothesis.

Dunhuang's sand mountains dwarf a wall of poplars planted to insulate the city from blowing sand and prevent their advancement.

-Yueya Quan-

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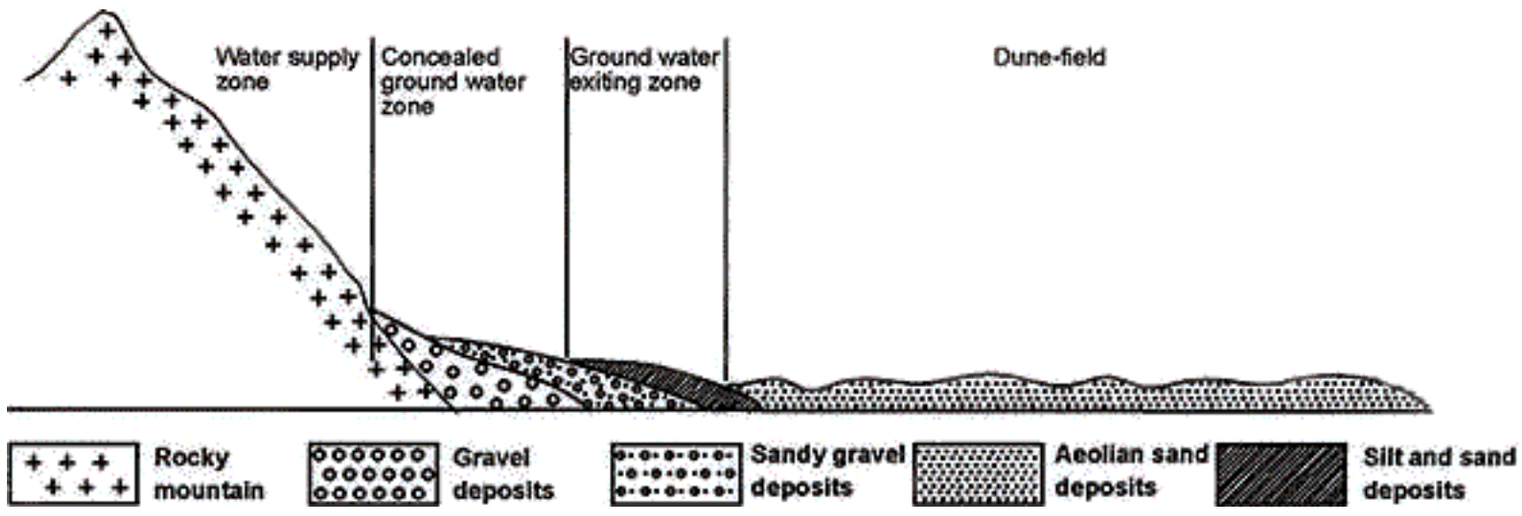
Yueya Quan

Though visitors are naturally drawn to Dunhuang's dunes for their striking beauty, they also come to see what has been termed in Chinese as Yueya Quan, or the crescent moon spring. Legend has it that this pool, fed by an underground spring, has existed in this same location for over 2000 years, in spite of the enormity of the shifting sand mountains surrounding it. Depicted here in afternoon sunlight, the small, crescent-shaped spring remains a tranquil sanctuary to the harsh winds and blowing sands of the surrounding dunes.

Yueya Quan, pictured above, is thought to have formed from an offshoot of the same groundwater system that created the Dunhuang oasis, namely groundwater flowing from the peaks of the Qilian Mountains that has surfaced in Dunhuang and its Mingshashan.

Geologists have attributed the mysterious presence of lakes like Yueya Quan to large supplies of groundwater that exist under the Gobi's surface. This groundwater is most likely derived itself from the same aquifer that the oasis of Dunhuang depends on, which is thought to originate in the southern Qilian mountains. Although glacier melt from the Qilian range channels a significant portion of its water into rivers like the Heihe and Dang rivers, a significant portion also seeps under loose gravel deposits surrounding the mountains, resulting in large deposits of ground water underneath the desert surface. Rather than a stagnant body, these groundwaters are constantly in slow motion, flowing in whichever direction they can most readily permeate their surrounding soils. Scientists believe that when these deposits of ground water encounter tightly packed, fine grained sediment that proves too dense to penetrate, they are forced to the surface, forming lakes such as Yueya Quan and oases like Dunhaung, Jiayuguan, and Zhangye.



Schematic view of water flow from mountain range to dune field. Spring fed lakes like Yueya Quan form when ground water encounters fine grained sediment such as silt or fine grained sand, forcing the ground water to exit within or next to a dune field. (Dong, 2003. Used with permission of the author.)

Moon Lake in China's Tenger Desert, another spring-fed body formed by groundwater forced to the surface. The source for this lake most likely originates to the east in Inner Mongolia's 3000+ m Helan range.

-Booming Sands-

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Booming Sands

In addition to the majesty of the Mingshashan and Yueya Quan, Dunhuang's singing sand mountains are also famous for their ability to generate a booming, thunder-like sound that forms when footsteps dislodge sand grains along ridges, sending sheets of cascading sand down the slipfaces of the dunes. Mildred Cable, a missionary in China, once described her experience with these booming sands in the early 1900's.

"The downward stretch of the soft slope was an irresistible inducement to slide, and we all came down with a rush, bringing the sand with us like a cataract. Then, for the first time, a loud noise came from the very depths of the hill on which we were, and simultaneously a strong vibration a strong vibration shook the dune as though the strings of some gigantic musical instrument were twanged beneath us. We had, unknowingly, chosen for our slide one of the resonant surfaces of the hill, for, curiously enough, only a few of the dunes are musical and most of them are as silent as they are dead."

Tourists climbing a ridgeline of Dunhuang's Mingshashan send miniature avalanches of sand down its slipface, occasionally instigating resonating sounds from the dunes.

Magic as it may seem, singing sand dunes like these are neither unique to Dunhuang nor an entirely mystical phenomenon. Scientists believe that the mystery behind such sound production is associated with particular properties of the sand grains that constitute the dune face. Specifically, researchers have discerned that sand dunes capable of these sound effects are usually constituted of medium grained, well sorted, smooth, and well-rounded grains with well polished faces. Furthermore, sand grains that resonate are also extremely dry, for as little as 1% moisture content between them can render their sound nearly inaudible. Although researchers have hypothesized a number of ways that attempt to explain the physics of sound production from these grains, the exact mechanics in which sand produces resonating sound remain poorly understood. In a sense then, the singing sand mountains of Dunhuang have retained some of their ambiguity even under the scrutiny of modern science.

-The Badain Jaran-

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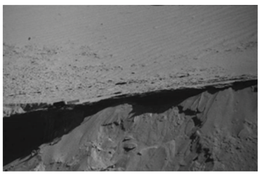
The Badain Jaran

Roughly 150 kilometers north of the Hexi corridor lies one of the most geologically fascinating and beautiful deserts in the world: the Badain Jaran. Covering an area of over 49,000 square kilometers, the Badain Jaran is home to the largest dunes on earth, the highest of which tower over 450 meters tall and stretch over 5 km in length. In addition to its megadunes, the Badain Jaran also boasts roughly 140 spring fed lakes that reside in the interspaces of the giant megadunes, creating one of the most captivating desert landscapes in the world. It is from these lakes that the Badain Jaran has derived its name, which means "mysterious lake" in the local Mongolian dialect. In spite of its striking beauty and geological significance, however, the Badain remains poorly studied due to its inaccessible location, and has only received focused attention from geologists in the last 2-3 years.

Megadunes of the Badain Jaran interspersed with spring-fed lakes. Scientists have documented that the crescentic dunes superimposed on the megadune faces often reach hights of 30 meters. (Dong, 2003. Used with permission of the author.)

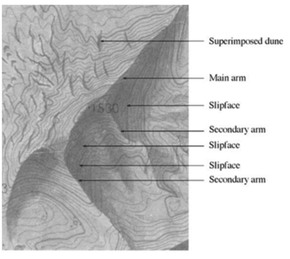
For years, scientists have wondered what natural forces have played a role in shaping such large megadunes. In 2000, a Chinese scientist found four layers of hard, cemented sand embedded with plant roots measuring .1-4 cm in diameter on one megadune in the southeastern portion of the desert. Hard, cemented layers like these in sand dunes are known to geologists as calcareous crusts, and are known to occur when precipitation in deserts reaches 100 to 350 mm per year. The cement in the layers of these crusts forms as a result of vegetation, which, through biological processes, dissolves calcium carbonate ($CaCO_3$) from surrounding sand grains and precipitates it in a manner which causes the grains to bind to one another. As a result of this concretionary process, hard, well-cemented layers of sand result. Calcareous crusts then, are strong evidence of wet and humid periods in desert history.



A hard calcareous crusts protrudes out over the soft sediment of an ancient dune. Such crusts prevent the movement of sands underneath them, fixing them in place for tens of thousands of years. (Yang, 2004. Used with permission of the author.)

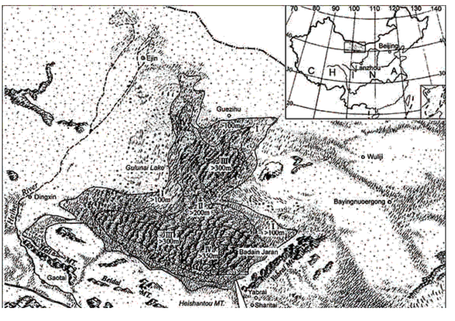
Although many thin layers of calcareous crust were found throughout the dune, only four of these demonstrated evidence of preserved root systems. Of them, the bottom layer was roughly .3-.4 m thick, while the other three thinned upwards, measuring 0.2 m, 0.1-0.2 m, and 0.02-0.08 m, respectively. Radiocarbon dating revealed that the roots in the lowest and thickest section were 31 thousand years old, while the remaining root systems dated to 19, 9, and 2 thousand years. Scientists have hypothesized that these periods represent times of increased precipitation and humidity in the Badain's paleohistory. Likewise, these calcareous crusts are thought to explain the massive size of the megadunes in this desert. During wet periods, geologists contend that vegetation populated dune surfaces, resulting in the formation of the calcareous crusts that exist there today. In the process, these crusts fixed the loose sands of the dunes beneath them, hindering them from futher movement. When the climate became arid again, loose sands blew over the calcareous crusts, covering them with new dunes. In this manner, geologists believe that the process of megadune construction in the Badain has been a cycle of growth and fixation with cyclical fluctuations in aridity and rainfall.

The Badain contains the largest dunes on earth, but the distribution of 400+ meter dunes is only dominant in the southeastern portion of the desert where star dunes are the predominate dune from. In the northwest of the desert, the dunes are smaller barchans, with elevations typically ranging between 150 and 300 meters. To add to the complexity, the 140 odd lakes in the Badain Jaran are all located in the southeastern portion of the desert among the larger stardunes. What could cause such dramatic variations across a single desert landscape?



A schematic interpretation of the magadunes of the Badain Jaran. Scientists contend that the secondary arms of these dunes are the result of surrounding mountain ranges interfering with the traditional northeasterly wind regimes of the desert. (Dong, 2003. Used with permission of the author.)

To address this question, one only needs to examine the Badain in its regional setting. Bordered by the Heli, Beidai, and Heishantou Mountains at its southern fringe and the Yabrai Mountains to its east, the Badain is flanked both to the south and east by mountains. Placed in this context, researchers have discerned that the 400+ m star dunes and their lakes in the southeast portion of the desert owe their existence to their adjacent mountain ranges. The transition from crescentic to star dunes toward the southeast corner of the Badain has thus been linked with these mountain ranges interfering with prevailing southeasterly winds here, resulting in the construction of star dunes.



Map of the Badain Jaran and its surrounding topography. The tallest megadunes and spring-fed lakes are concentrated in the southeast corner of the desert, nearby the Yabrai and Heishantou Mountain ranges. (Dong, 2003. Used with permission of the author.)

Similarly, scientists believe that these same snow-capped ranges play a crucial role in supplying the Badain's lakes with water. Even at their moderate elevations, these mountains collect significant amounts of water, channeling it down their flanks and underneath gravel deposits at their base. As a result, these ranges have created large scale deposits of ground water flowing underneath the Badain's surface over their geological history. When such ground water encounters densely packed, fine-grained material like the dunes of the Badain, it is immediately driven to the surface, resulting in the lakes we see today.

A spring-fed lake in the Badain Jaran. The red color of the water is caused by bacteria that have adapted to its hypersaline environment. Though testing has revealed that the springs that feed these lakes contain fresh water, the evaporation rate of 2400 mm per year that occurs here has concentated their mineral content to the point where the water has become hypersaline. (Dong, 2003. Used with permission of the author.)

-Yardangs-

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Yardangs

A few hundred kilometers west of Dunhuang lies a yardang field, another striking geological formation of China's deserts. The term yardang was introduced in 1903 by a Chinese scientist who stumbled on the formation while exploring Lop Nor, the eastern region of the Taklimikan desert. His named his discovery after what locals termed them - yardangs - literally meaning steep precipitous hill in the local Uighur dialect. In recent years, a road has been constructed to this yardang field outside of Dunhuang for the production two Chinese movies, "Hero" and "The Touch," and is now accessible to tourists by a bus from Dunhuang that runs once a week.

Unvegetated gobi flank both sides of this newly constructed road to the yardang field.

The author and surrounding yardang field.

Yardangs form by processes of wind erosion in regions where prevailing winds are typically unidirectional. Yardang fields have also been found on Mars, but their presence there has generally been associated with katabatic currents, or winds which downwell into depressions. Though much of their geology remains poorly understood, yardangs are limited to regions of extremely high aridity, where winds outpace water erosion.

Yardangs generally have a blunt, steep, and tall front that faces into the wind, and a trailing backside that gradually tapers backwards to form a point near the ground. Due to this aerodynamic profile, yardangs are thought to evolve from wind and sand abrasion sculpting their form. Laboratory experimentation has determined that yardangs exhibit minimal aerodynamic resistance at a 4:1 length:width ratio, but few yardangs in nature actually demonstrate this trend, indicating that other factors outside of wind erosion may play a role in their formation.

Globally, yardangs vary widely in composition, and can form in sandstones, limestones, clays, granites, gneisses, schists, and lacustrine (lake) deposits. With the exception of Australia, yardangs are found in deserts worldwide, as well as on Mars, but are rare, probably due to their need for extremely arid conditions and unidirectional winds. The largest yardang field on earth is located in China's Qaidim depression.

Yardangs generally have a steep, blunt end facing into the wind (above) and a gradually tapering tail (below).

Although most yardangs are aerodynamically shaped, outliers do exist. Winds erosion has entrenched the earth around this yardang into a depression, a feature only observed in structures outside of the main field. The rubble pile in the background may have once been linked with this standing structure.

-Shapotou-

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Shapotou

Some 1400 km and three days east of Dunhuang lies Zhongwei County. There, situated along the Yellow River is the beautiful town of Shapotou, a place that has ironically embraced its surrounding desert as a source of tourism while simultaneously invested in finding ways to revert its sands back into fertile farmland.

Camel riding at Shapotou's desert theme park.

Next to the dunes, lies the Shapotou desert theme park where tourists gather for activities in camel riding, horse riding, dune tobogganing (complete with a chairlift), swimming and rafting. To top if off, the town also boasts China's first zip line, allowing intrepid tourists the chance to soar across the Yellow River. Just before the entrance to the park, however, is one of the oldest and most important desert research stations in China.

The entrance to the Chinese Acadamy of Science's Shapotou Desert Research and Experimental Station.

Traditionally, desertification and land reclamation studies in China have been undertaken by the Institute of Desert Research of Academia Sinica (IDRAS), which has its headquarters in Lanzhou and nine field stations around country, one of which is here in Shapotou. Established in 1957, the desertification research facility at Shapotou was originally founded in order to find a means for preventing sands from overrunning a 40 km stretch of rail line near Shapotou and causing serious train accidents. Over the course of its inception, the desert research station at Shapotou has experimented with a variety of methods for controlling desertification, including windbreaks, irrigation with sediment rich water, straw checkerboards, indigenous plants, the extraction of ancient soils (palaeosols) underlying dune surfaces, and chemical treatment processes. Among these, the construction of straw checkerboards over dune surfaces has proven perhaps the most cost-effective and most commonly used method for fixing encroaching sands.

Straw checkboards are constructed along a road in the Tenger Desert.

To begin the stabilization process, windbreaks of willow branches or bamboo are initially installed upwind from the desired area of protection. Such breaks are instrumental in slowing down sand laden winds from surrounding sandy lands, causing them to drop out their sediment load before reaching the area of desired protection. Behind the windbreak, wheat or rice straw is driven roughly 20 cm into the sand, with another 10-15 cm left sticking out into a square grid. As a consequence, the surface roughness of the dunes is greatly increased, which slows down winds passing over them and prevents sand from being picked up off of their surface. Experimentation with a variety of grid sizes for these straw grids has demonstrated that they are most effective when embedded in checkerboard squares that are 1 square meter or less in area. When properly constructed, these straw blankets decrease sand transport over dune surfaces by a hundred fold.

Although such checkerboards only last 4-5 years, they fix dunes sufficiently well for a few specialized species of plants to grow on the dunes. Among them, the Shapotou research station has experienced most success with Agriophyllum squarrosum, Bassia dasyphylla and Corispermum hyssopifolium. Once such specialized forms of vegetation become established, their presence further contributes to the stabilization process by reducing wind speeds across the dune surface, generating organic matter on the dunes, and by stabilizing the dune surface through root growth.

As a result of inceased shading from vegetation, lower wind speeds, and stabilized sands, thin (1-3 mm) gray algae surfaces begin to naturally develop on the surfaces of the dunes. Such algae crusts prove particularly important for further stabilization as they decrease runoff during rainfall and increase water absorption into the dune surface. Consequently, a far more suitable environment is created for wind blown seeds to germinate, resulting in further stabilization of the dune. Without such algae blankets, however, rainfall on dunes usually forms a thin crust that prevents water from permeating the surface layer, resulting in poor absorption, rain splash, and runoff. Luckily, once this algae layer is established, it proves relatively durable, and can live through drought on the dune surface for prolonged periods of time.

The entire process of dune fixation, from the installment of straw grids to the establishment of a stable algal crust takes approximately six years. Once such cover has been established, additional shrub species naturally find their way onto the surface of these dunes, completing the reclamation process.

Straw checkerboards and their windbreak protect the Lanzhou-Baotou rail line from blowing sands. Here, natural vegatation has already established itself permanently on many surfaces of the dunes, showing that given ample time and effort, desert reclamation is possible.

Other methods for reclaiming desertified lands have been established, but require more stringent conditions for implementation. One such strategy has been to flatten dunes, either by human labor or bulldozer, and irrigate them regularly with water from the Yellow River. Stretching for 5464 km, the Yellow River (Huang He) is the world's most heavily sedimented, channeling 1.6 billion tons of sediment into the Yellow Sea every year. By regularly irrigating these fields with water heavily stratified with such silt and adding sheep manure, scientists were able to deposit roughly 40 cm of topsoil on the sand in a twenty-five year period. Though effective, the process requires relative proximity to the Yellow River and significant time, two luxuries which many farmers don't have.

One other practical method, however, has been determined for reclaiming desertified land, particularly for farmers who live in the Mu Us desert. Although now much of this desert is covered in sand, as early as 300 years ago it was fertile grassland. As a result, in some areas fertile soil can be uncovered from underneath overlying sands and mixed with surface sand dunes and sheep manure. In some areas, lands reclaimed in this fashion have been able to produce good crops of maize, wheat, soybeans, and other vegetables only 2-3 years after reclamation. Compared to other processes, this remains the only one that has proven extremely cheap, relatively quick, and effective.

-Yinchuan to Hongsibao-

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Yinchuan to Hongsibao

Further down the Yellow River is situated the city of Yinchuan, capitol of Ningxia province. Rich with water from the Huanghe, or Yellow River, Yinchuan is a prosperous and rapidly growing city. Outside its busy streets and shopping districts, farmers have sufficient water to plant rice, a crop that would be impossible to grow here were it not for the Yellow River.

Rice fields of Yinchuan are sustained by the waters of the Yellow River.

Just three hours south of Yinchuan, however, stands a brand new village that has been entirely planned, built, and funded by the Chinese government. The new town is a relocation center for farmers in Ningxia province who simply can't survive on the lands on which they have traditionally been living for generations. Altogether, the town holds roughly 100,000 people from eight different counties in Ningxia, and is still growing. Though the land here is arid, irrigation has been made readily available by canals that transport water from neighboring Yellow river, and farmers have little to fear.

Construction has brought a wealth of new jobs to Hongsibao and the surrounding region.

Just outside the central town, local construction workers build concrete casts to serve as irrigation ditches that will carry water to the surrounding croplands. Workers build tens of thousands of these molds, which are then assembled in small trenches as irrigation channels. Construction has done wonders for families that have moved here in recent years, providing plenty of work for the town's youth while older farmers tend to their fields.

Farmers assemble cement pieces (pictured above) into irrigation channels for their fields.

These women, pictured here in front of their new home, came here three years ago from Ningxia's southern county of Xiji by army car. Roughly one hundred other families came with them, and upon their arrival each was provided with a free home. Back in Xiji, their well had gone dry and regular sandstorms were proving too strong for their corn. Life here, they say, has proven far easier.

In the mountains where he used to live, this man claims that there is so little rainfall that many try to earn a living just by planting trees for the government. Back at his old home, he used to "plant and plant", but the land simply never gave anything back. Even though he has just 8 mu of land here, he remains confident that it will be more than enough to live on. To find a home in Hongsibao, one must first apply by sending a letter to the government, and then wait for their final decision. Many families are turned down. Though the town is still developing and management is poor, he recognizes that he and his son have a brighter future here.

A physics teacher for his local village, this man says he manages to earn 1,200 Chinese yuan, or $150 per year, more than most in his community.

This Hui couple, an ethnic minority in China, arrived in Hongsu two years ago by bus. Although they only own 8 mu of land, the soil is much better here than where they used to live, and their son has found reliable work in construction for the new town.

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Concluding Remarks

In spite of the challenges faced by farmers and herdsmen throughout China's Hexi corridor, locals nevertheless demonstrated a keen sense of determination to maintain their hold over their lands and continue their traditional ways of life. No matter how sandy the soil, how close the dunes, or how fierce the sandstorms, farmers unanimously seemed to find the means to carve out a miniature plot of land to cultivate, using every last inch of arable soil to make a living out of nothing. Granted their resolve, it seems that they may indeed be able to continue facing the trials of desertification for generations to come, but to ease their struggle, certain measures need to be taken.

To increase productivity of land, farmers need to recognize that regular irrigation by field flooding can easily lead to increased alkaline and salt concentrations on their soil, and decrease the productivity of their crops. Furthermore, crops need to be rotated more frequently on plots of land and be given regular interims from planting to properly rejuvenate their nutrient content. Livestock need to be penned in specified areas to limit their disturbance to root systems and vegetation that have proven important actors in preventing the soil erosion and land degradation. Similarly, firewood collection needs to be limited only to dead woods, and alternative forms of energy need to be promoted by government in rural areas. Finally, farmers and government alike need to be aware that the reclamation process is a costly and time consuming endeavor, but can ultimately succeed if proper measures are taken.

Water parks like this one in Jiayuguan exist in spite of the region's problems with desertification.

Lost, a Bactrian camel stands amidst a farmer's field.

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Acknowledgements & Bibliography

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Shapotou Yinchuan to Hongsibao Concluding Remarks Bibliography & Acknowledgements