Sarah Simpson is a freelance writer and contributing editor for *Scientific American*. She lives in Riverside, Calif.

GEOLOGY

AFGHANISTAN'S BURIED RICHES

Geologists say newfound deposits in the embattled country could fulfill the world's desire for rare-earth and critical minerals and end opium's local stranglehold in the process

By Sarah Simpson

THE SCENE AT FIRST RESEMBLES MANY THAT play out daily in the war-torn Red Zone of southern Afghanistan: a pair of Black Hawk helicopters descend on a hillside near the country's southern border with Pakistan. As the choppers land, U.S. marines leap out, assault rifles ready. But then geologists sporting helmets and heavy ceramic vests jump out, too. The researchers are virtually indistinguishable from the soldiers except that they carry rock hammers instead of guns. A human chain of soldiers encircles the scientists as they step forward on the dusty ground.

"The minute you get off, you go into geologist mode," says Jack H. Medlin, director of the U.S. Geological Survey's activities in Afghanistan. "You forget, basically, that these guys are around—unless you try to get out of the circle."

Medlin's team has flown many missions, each one limited to an hour so that hostile forces do not have time to organize and descend. Sixty minutes is a stressful, fleeting instant to geologists who would typically take days to carefully sample and map a site. The rocks con-

IN BRIEF

Under military cover, U.S. geologists have mapped Afghanistan's deposits of critical minerals. Rich reserves of rare-earth elements exist in the south, where Taliban control is tightest.

If mining of important minerals can take off in the north, that success could create enormous commercial and political momentum for opening the south. New estimates indicate that rare earths could be triple the initial predictions.

Overcoming the country's opium and Taliban strongholds with a mining bonanza could change U.S. foreign policy and world stability.

Over the long term, Afghanistan's geologists will have to take charge. The U.S. Geological Survey is nearly done training them.

MOISES SAMAN *Redux Pictures*

Desolate hills in southern Afghanistan could harbor enough rare-earth elements to supply the world for years.

taining a desirable element—say, gold or neodymium—are invariably sandwiched between less interesting ones, all of which were laid down long ago and since folded, buried and exhumed so that they protrude only here and there, possibly in deeply eroded streambeds or on opposite sides of a steep valley. Following the trail takes expertise, stamina and concentration. The marines know that their protégés pursue the clues like bloodhounds, so the human circle moves with the scientists.

The latest of these gutsy excursions, carried out in February, proved that the missions have been worth the risks. It revealed a superlative cache of rare-earth elements—a coveted subset of so-called critical minerals that have become essential to high-tech manufacturing and yet are in short supply in the U.S. and many nations. The prized deposit is comparable to the premier site mined in China.

Geologists long had hints that Afghanistan was rife with massive, untapped stores of critical minerals worth billions or even trillions of dollars. And political leaders knew that if the volume of minerals was extractable, the wealth might allow Afghanistan's economy to transition away from its dependence on opium production, making the country more politically stable. But before any mining company will dig in, someone has to figure out whether the deposits hold enough treasure to be worth the cost. That means putting boots to dirt: collecting samples and mapping the rocks in detail. The USGS has now compiled reams of data from its dangerous forays into regions around the country. After high-level talks with Medlin about the latest information, senior officials at the U.S. Department of Defense and Department of State have become convinced that mineral riches could well help to transform Afghanistan. Indeed, a land rush of sorts has already begun. A major mining company from China has called dibs on a huge copper deposit in a $2.9-billion venture that is now Afghanistan's largest development project. U.S. interests have invested in gold. And Indian firms are the majority of almost two dozen that are clamoring for iron.

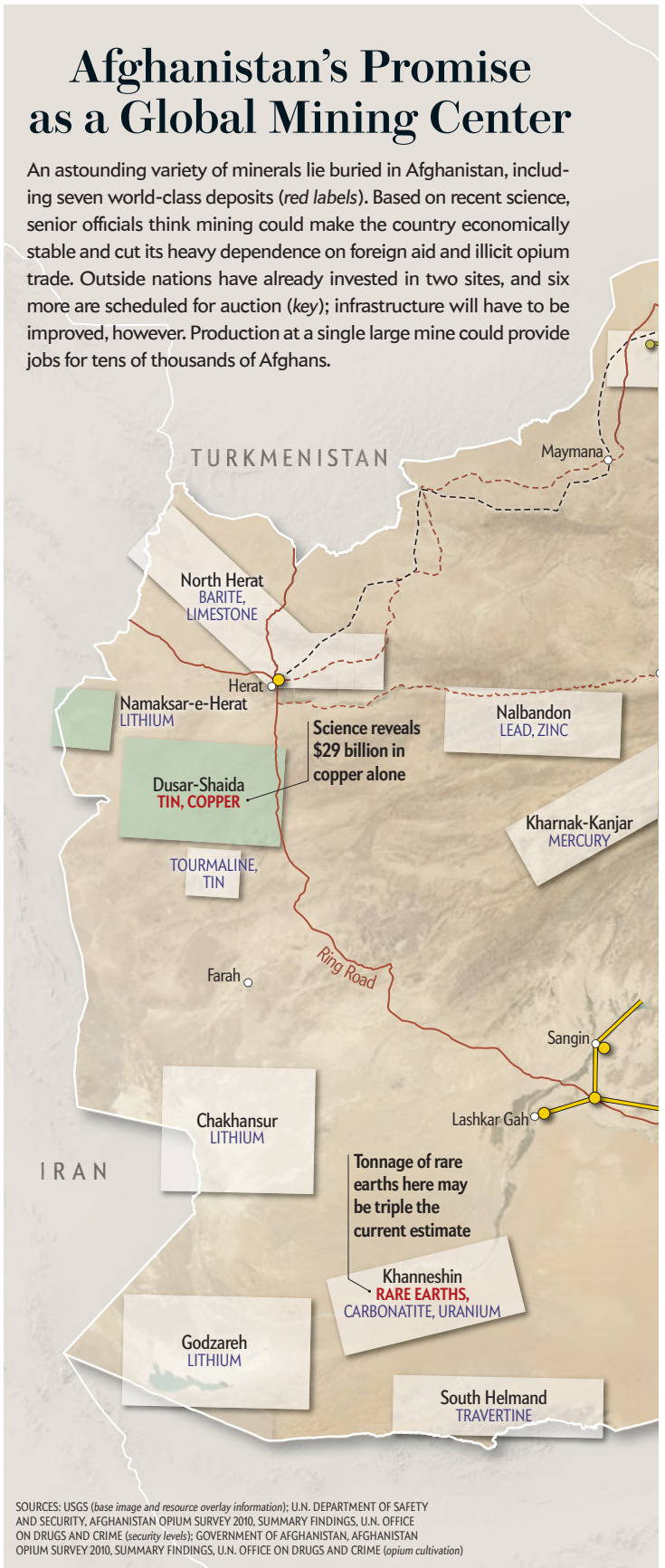
The USGS's latest assessments of the nation's mineral bounty were to be made public in a landmark report rolled out in Kabul and at the Afghan embassy in Washington, D.C., at the end of September. But as of August, when this article was being written, Medlin and other USGS scientists had already told me that the concentration and access of Afghanistan's minerals could make the country one of the most important mining centers on earth. Notably, Afghanistan could become a major supplier of rare earths as China hoards its own. How soon foreign investors will be willing to mine for those elements is unclear, however. The site examined in February lies in the southern part of the country—the most violent region, under the strongest Taliban control. Yet if mining of copper and other metals can take off in the north, that surge could create an enormous commercial and political "gold rush" that could finally help drive out the opium and Taliban strongholds, possibly creating a dramatic shift in U.S. military action and foreign policy and a blow to terrorism.

Such a prospect could never have become a serious possibility if geologists had not made extraordinary efforts to do science in a war zone—a story that has gone largely untold until now. Medlin and 50 other USGS scientists have been exploring Afghanistan for seven years and have gone to great lengths to train the country's geologists to do the same work on their own. Medlin and others will be back in Kabul in the coming months, helping Af-

MINERAL WEALTH

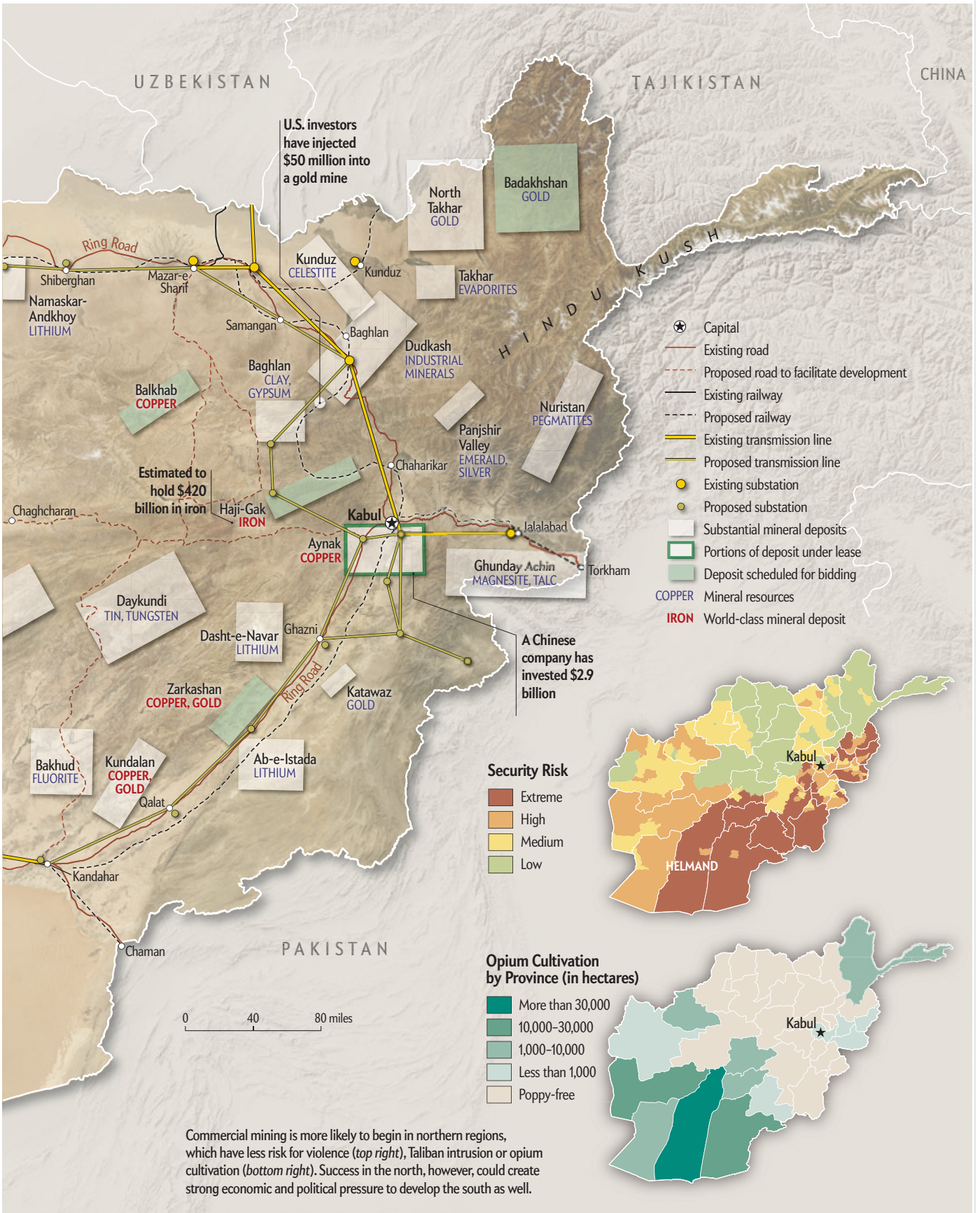
Afghanistan's Promise as a Global Mining Center

An astounding variety of minerals lie buried in Afghanistan, including seven world-class deposits (*red labels*). Based on recent science, senior officials think mining could make the country economically stable and cut its heavy dependence on foreign aid and illicit opium trade. Outside nations have already invested in two sites, and six more are scheduled for auction (*key*); infrastructure will have to be improved, however. Production at a single large mine could provide jobs for tens of thousands of Afghans.



SOURCES: USGS (*base image and resource overlay information*); U.N. DEPARTMENT OF SAFETY AND SECURITY, AFGHANISTAN OPIUM SURVEY 2010, SUMMARY FINDINGS, U.N. OFFICE ON DRUGS AND CRIME (*security levels*); GOVERNMENT OF AFGHANISTAN, AFGHANISTAN OPIUM SURVEY 2010, SUMMARY FINDINGS, U.N. OFFICE ON DRUGS AND CRIME (*opium cultivation*)

Map by XNR Productions



Commercial mining is more likely to begin in northern regions, which have less risk for violence (*top right*), Taliban intrusion or opium cultivation (*bottom right*). Success in the north, however, could create strong economic and political pressure to develop the south as well.

ghan scientists to interpret the latest reports and make practical determinations about dozens of new mineral deposits. And plans are afoot to take an even deeper look at the rare-earth find, which they suspect is much larger than the initial estimate suggests.

RARE (EARTH) FINDS

FOR DECADES most assertions about Afghanistan's mineral worth were guesswork. In 2007 Medlin's team had identified the 24 most promising mining regions throughout Afghanistan's arid plains and high mountains, based on painstaking integration of unpublished field reports from the Soviet era and before. But the governments of both the U.S. and Afghanistan basically ignored the information until two years later, when Paul A. Brinkley took notice. A U.S. under secretary of defense who had overseen the Pentagon's efforts to boost business in Iraq and Afghanistan, Brinkley figured that minerals were the best bet for beating opium, and he asked Medlin for help. Medlin knew it would take much more sophisticated science to entice mining companies to bid for sites. Companies typically invest lots of money determining whether to mine a given site, and most of them would not send their own scientists into a war zone.

In 2009 Brinkley's task force called on Medlin to do just that. Since then, the USGS has used satellite imagery, remote-sensing surveys and on-the-ground fieldwork under military cover to vet old estimates and pinpoint the most promising new deposits. Medlin can now say with certainty that at least half a dozen metal deposits are equivalent to those being exploited at the most productive mines around the world.

The rocks flush with rare-earth elements are situated near the heart of a dead volcano in the dry southern plains of Helmand province, not far from the village of Khanneshin. The volcanic landscape would be tricky for a geologist to navigate on foot even without the possibility of hostile militants hiding around the next crag. USGS scientists have been motivated to risk visiting the volcano, which is well within the Red Zone, in part, by the groundswell of concern about how the world's industries will feed their ever increasing need for critical elements. China currently provides 97 percent of the world's rare-earth supply, which makes other industrial countries nervous, particularly considering its recent slashing of exports to Japan [*see box on page 64*]. Global demand for other minerals is also soaring, and prices are rising with it. A decade ago copper was about 80 cents per pound; it is now roughly $4.

Medlin's crew had tried, during two earlier marine-chaperoned visits to the volcano, to verify Soviet-era claims that rocks containing the prized metals existed there. In February the team discovered a sizable swath of rocks enriched in the so-called light rare-earth elements—including the cerium used in flat-screen TVs and the neodymium used in high-strength magnets for hybrid cars.

So far the team has mapped 1.3 million metric tons of the desirable rock in Khanneshin, holding enough rare earths to supply current world demand for 10 years. The Pentagon has estimated its value at around $7.4 billion. Another $82 billion in other critical elements may be at the site. With more time on the ground and the right kind of geophysical surveys, the scientists suspect they would discover that the rare-earth deposit could be two or three times more massive. Looking across a steep valley they did not have time to explore, the geologists say they could see what was almost certainly a continuation of the same rock formation. High-altitude imagery that measures variations in the magnetism and density of deeply buried rocks suggests the desirable material probably goes much deeper as well.

Any mining at the Khanneshin volcano would probably still be years off, however. Afghanistan has little experience with heavy industry, no real railroads and hardly any electrical power in rural areas. Those challenges are not the problem, though; major mining companies are accustomed to pioneering undeveloped frontiers in remote parts of Indonesia, Chile and Australia, for example. The need for exceptional security against hostile forces is the potential deal breaker. Coalition forces passed control of the provincial capital, Lashkar Gah, to Afghan security forces in July, making regional safety even more uncertain.

HEAVY METAL

RIGHT NOW the multibillion-dollar investments needed to open mining in Afghanistan are more palatable in the northern half of the country, where danger is less immediate, Medlin says. And that is not a bad deal. Those areas harbor untapped masses of rock containing copper, gold and iron worth hundreds of billions of dollars. Afghanistan's Ministry of Mines is keen to inspire a landgrab for those commodities. The first bite came in 2007, when China Metallurgical Group outbid four other foreign investors for a lease to develop a copper deposit known as Aynak in the mountains south of Kabul. Expecting the deposit to provide $43 billion over the life of the mine, the company agreed to build two power plants to drive mining equipment and supplement the regional power grid, as well as a portion of the railroad needed to link the mine to existing rail lines in the former Soviet republics to the north.

Further interest in the country's minerals stalled, however, until Brinkley got involved. Based on new details that Medlin's team collected, the Pentagon has reinvigorated interest by hiring a major mining-consulting firm to compile information on the most promising sites in a format attractive to foreign investors. Late last year these efforts paid off. Western investors, led by the chair of J. P. Morgan Capital Markets, injected $50 million into a small artisanal gold prospect in an alpine valley east of Mazar-e Sharif. The goal is to get a mine up and running with local labor and modern equipment by early next year.

More activity may arise soon. With the help of the Pentagon and the World Bank, Afghanistan's Ministry of Mines intends to begin auctioning off six other major mineral tracts by the end of the year. First is Afghanistan's most potentially lucrative stash: iron concentrated in Haji-Gak, mountainous terrain about 130 kilometers west of Kabul (and conveniently close to the planned railroad northward from Aynak). Estimated at a whopping $420 billion, the resource could bring in $300 million in government revenue each year and employ 30,000 people, according to the Afghan ministry. Like many of the nation's buried riches, portions of this vast deposit, which crops out in easily visible, dark black rocks, were discovered more than a century ago, but Afghanistan has never had the right combination of wherewithal, inclination and stability to start a major mining operation. Now it has taken the first step: enticing foreign investors. Bids were due in early September from the 23 international mining companies that lodged formal expressions of interest with the Afghan government late last year, including the Chinese Aynak contract winners.

Geologists Said Mirzad (*far left*) and Stephen Peters track rare-earth elements in southern Afghanistan as U.S. Marines guard against Taliban fighters. Deposits of copper (*above*) much farther west could be worth $29 billion.

COURTESY OF USGS

TAKING OVER

SUCCESSFULLY CLOSING these and other deals will require still more geology, and Afghanistan's scientists need to take charge. Bringing them up to speed on modern science and information technology was the USGS's primary goal in first entering the country (and still is). That goal motivates Medlin and a close USGS colleague, Said Mirzad, an Afghan-American geologist who visited the Haji-Gak iron deposit more than 30 years ago when he was director of the Afghanistan Geological Survey. Mirzad says he had a clear vision of trucking Haji-Gak's iron ore to Pakistan or possibly developing a local steel mill. But the 1979 Soviet invasion and subsequent occupation cut that dream short. The Soviets imprisoned Mirzad multiple times before he finally fled to the U.S. with his wife and two young sons in 1981. The country's scientific capacity stagnated in the decades of strife that ensued.

The 2001 U.S. invasion opened the door. Within three weeks of the September 11 terrorist attacks, Mirzad and Medlin received authorization—and, later, funding from the U.S. Agency for International Development—to help the Afghans firmly establish what natural resources lay buried in their native soil and to train scientists who could help advise the government about exploiting those resources. Such activities are typical work of the USGS, which has helped dozens of troubled countries rebuild their natural-resources sectors. Medlin's team knew next to nothing about the world-class potential of Afghanistan's copper and rare-earth deposits, and minerals certainly were not yet seen as a competitor to opium.

"After 25 years of war, we had no idea if there would be any geologists in Kabul when we got there," recalls Mirzad, who accompanied Medlin and seven other Americans on the first USGS visit in 2004. When they arrived at the headquarters of the Afghanistan Geological Survey, they found a bombed-out, pockmarked shell next to a slaughterhouse. There were no windows, doors, plumbing or electricity. Bullet holes studded the walls; a rocket had passed clean through the director's office. Still, roughly 100 geologists and engineers were coming into work a few hours a day, mainly to sort old reports they had hidden at home during the Taliban regime. Many of them cobbled together an income by selling cigarettes or driving taxis. Happily, their basic science training was very good. What they were missing was knowledge of the scientific and technological advances that had been developed since the early 1980s. One Afghan chemist recoiled when someone pulled out a laptop: "She wouldn't touch it, because she was afraid it would electrocute her," Medlin recalls.

Teaching the Afghan scientists the fundamental concept of plate tectonics was central. This theory—that the planet's crust is broken up, like a jigsaw puzzle, into pieces that move and crash together—revolutionized understanding of the earth in the years after the Afghans were cut off from the outside world. It explains why earthquakes occur, volcanoes erupt and mountains rise up. It also explains why Afghanistan, slightly smaller than Texas, is so unusually rife with minerals. Much of the now landlocked country formed through collisions of four or five crust pieces. These convergent boundaries tend to be where many of the world's major metal deposits occur.

One exercise the scientists hope to carry out is a detailed geophysical survey over the Khanneshin volcano. Medlin's crew, with the U.S. Naval Research Laboratory, had conducted airborne surveys from a high-flying NP-3D aircraft based on craft used for hunting down enemy submarines during the cold war. By charting the earth's magnetism and other properties, the geophysicists generated three-dimensional views of the uppermost 10 kilometers of Afghanistan's bedrock. Flown slowly and at lower altitude, the same instruments could discern far greater detail, revealing how specific mineral deposits extend down into the ground. The $7.4-billion estimate for the rare earths there assumes, very conservatively, that the rock is only 100 meters thick. It could easily be thicker. Medlin had hoped to do that survey, but the security clearance never came—too much risk of the plane being shot down, he assumes. So he convinced Brinkley to buy the Afghanistan Geological Survey the same instruments that can be carried on foot, and Medlin is bringing Afghan geologists to the U.S. to learn how to use them.

Medlin and Mirzad are both pleased with a $6.5-million renovation of the Afghanistan Geological Survey headquarters building in Kabul, which has left it looking as good as its American counterpart in northern Virginia, Mirzad says. "And the cafeteria is better," he adds with a wink. The Afghan agency now houses a

state-of-the-art digital data center and employs 100 full-time scientists and engineers who are conducting mineral-assessment surveys on their own. The Afghans' recent fieldwork at a copper deposit near Dusar-Shaida is the main reason it is included among those scheduled for upcoming bidding, Medlin says.

FORMIDABLE CHALLENGES

THE ADVANCING SCIENCE makes it clear that lucrative mining is finally possible in Afghanistan, and for the first time major investors are poised to commit. A national economy driven by mining could end opium's dominance and help to stabilize the country, which would give the U.S. and other nations good reason to scale back their heavy military involvement there.

Even so, some Afghans worry about whether mining would be good for the nation's people. Major mineral exploitation in some poor countries has been more curse than blessing. The discovery of oil in Nigeria more than 50 years ago has earned billions of dollars for petroleum companies and the government, but most Nigerians still live on less than $1 a day. Development could fuel Taliban resurgence and government corruption. Medlin promotes an "absolute imperative for transparency" as one safeguard; all the raw data the USGS has so carefully compiled are owned by the Afghan government, which permits the U.S. government to make the information available on the Internet.

Environmental protection is another concern. In many parts of the world where massive open-pit mining operations exist, authorities face decades of accumulated contaminants that must be cleaned up. Standard procedures for extracting rare-earth elements, for example, leave rubble strewn with uranium and other radioactive debris that threaten health. Transforming Afghanistan into one of the world's major mining centers without similar consequences will require serious forethought and accountability.

These challenges, and final determinations about which specific deposits are worth mining, are expected to fall mainly to Afghan scientists from now on. The USGS's Pentagon funding runs out at the start of the new fiscal year in October, and without military protection fieldwork for USGS scientists will be next to impossible. Native Afghan scientists travel more freely, so Medlin's team will do its best to advise them as they generate more detailed information. To keep up the momentum, Medlin has secured $8.7 million from USAID to continue processing the satellite imagery and other remote-sensing data the USGS has already collected to spot more promising deposits. "It's basically like picking out a dime in a million pennies," Medlin says. "We're seeing mineral-deposit anomalies that the Soviets and Afghans never knew existed."

Whether newly trained scientists and politicians can follow through with business development is unclear. Luckily, the rocks can wait. They have all the time in the world. SA

MORE TO EXPLORE

Afghanistan Geological Survey: www.bgs.ac.uk/afghanminerals
Afghanistan's Ministry of Mines: http://mom.gov.af/en
U.S. Task Force for Business and Stability Operations: http://tfbso.defense.gov
USGS Projects in Afghanistan: http://afghanistan.cr.usgs.gov

SCIENTIFIC AMERICAN ONLINE
For a discussion about mining complications and a slide show on exploration, see ScientificAmerican.com/oct2011/afghanistan

RARE EARTHS AND CRITICAL MINERALS

Global Demand Stresses Limited Supply

By Mark Fischetti, staff editor

A mere few countries control worldwide production of many minerals that have become essential to high-tech manufacturing: europium for TV displays, neodymium for computer disk drives. And some countries, such as China, have begun hoarding the resources for their own companies.

As a result, industrial nations are becoming increasingly tense about their sources of "critical elements"—minerals that are crucial but whose supply could be restricted. Most critical for the U.S. are the six elements in the platinum group of metals, the 17 elements known as rare-earth elements, as well as indium, manganese and niobium, according to the U.S. Geological Survey. Which nations have them (*top right*), and how dependent the U.S. is (*bottom right*), could affect the American economy and national security (in the case of military products) if trade is curtailed or new deposits are not found. More mapping is needed to determine the impact of Afghanistan's potentially vast resources.

What Are They Used For?

PLATINUM GROUP METALS

Platinum	Catalytic converters, electronics, chemical processing
Palladium	Catalytic converters, capacitors, carbon monoxide sensors
Rhodium	Catalytic converters, chemical processing
Ruthenium	Electronic contacts and resistors, superalloys
Iridium	Spark plugs, alloys, chemical processing
Osmium	Electronic contacts, electron microscopy, surgical implants

RARE-EARTH ELEMENTS

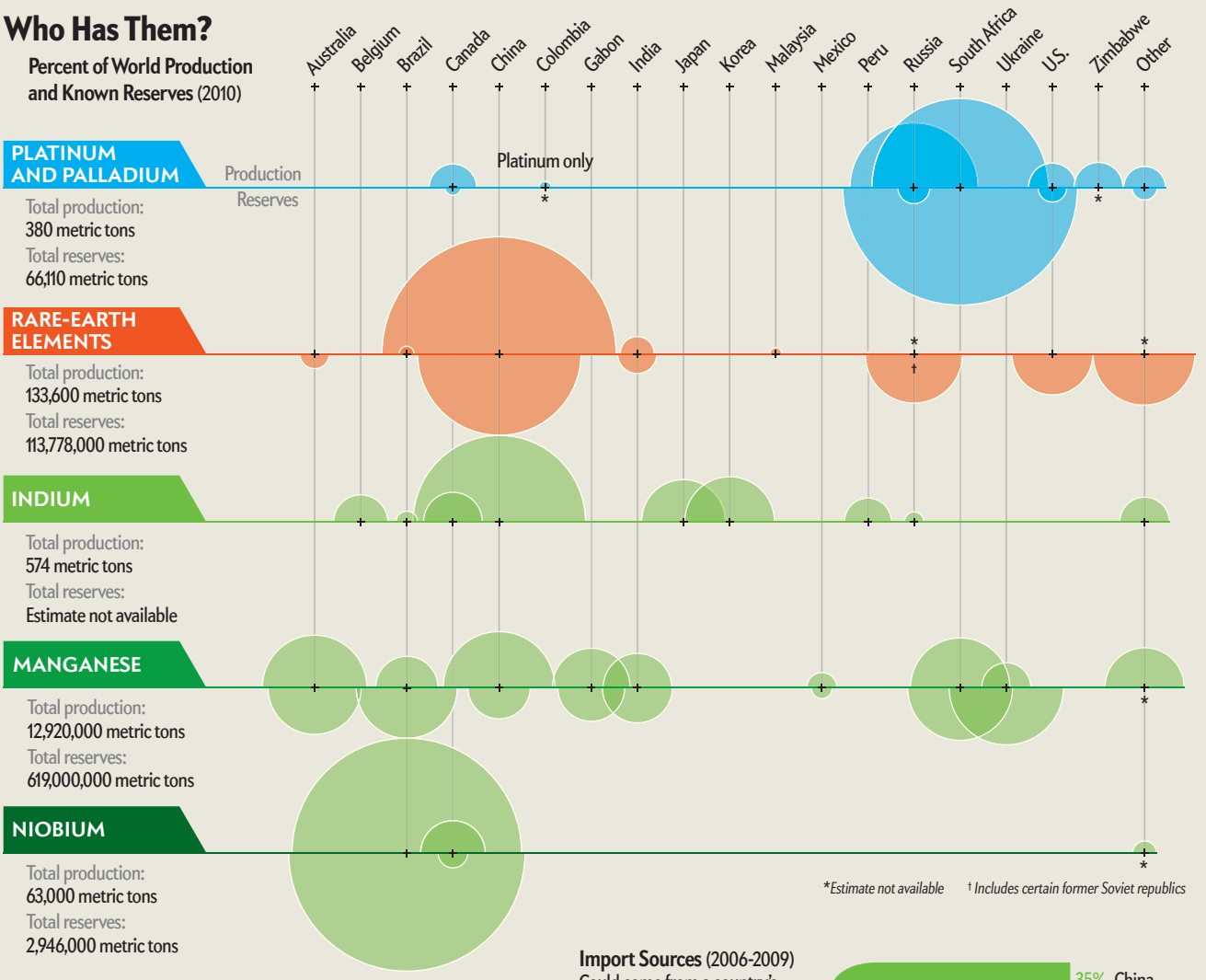
Scandium	Aerospace components, aluminum alloys
Yttrium	Lasers, TV and computer displays, microwave filters
Lanthanum	Oil refining, hybrid-car batteries, camera lenses
Cerium	Catalytic converters, oil refining, glass-lens production
Praseodymium	Aircraft engines, carbon arc lights
Neodymium	Computer hard drives, cell phones, high-power magnets
Promethium	Portable x-ray machines, nuclear batteries
Samarium	High-power magnets, ethanol, PCB cleansers
Europium	TV and computer displays, lasers, optical electronics
Gadolinium	Cancer therapy, MRI contrast agent
Terbium	Solid-state electronics, sonar systems
Dysprosium	Lasers, nuclear-reactor control rods, high-power magnets
Holmium	High-power magnets, lasers
Erbium	Fiber optics, nuclear-reactor control rods
Thulium	X-ray machines, superconductors
Ytterbium	Portable x-ray machines, lasers
Lutetium	Chemical processing, LED lightbulbs

OTHER CRITICAL MINERALS

Indium	Liquid-crystal displays, semiconductors, solar thin films
Manganese	Iron and steel production, aluminum alloys
Niobium	Steel production, aerospace alloys

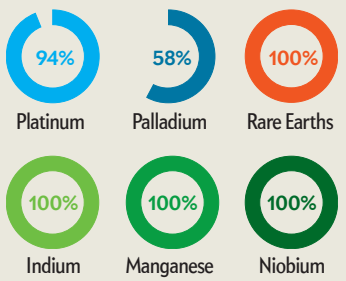
Who Has Them?

Percent of World Production and Known Reserves (2010)



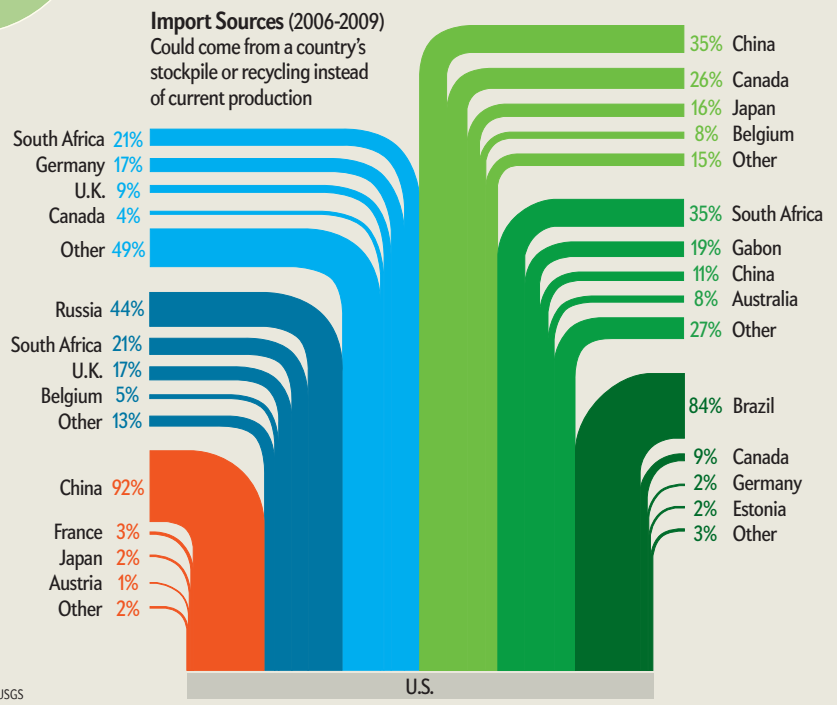
How Dependent Is the U.S.?

U.S. Dependence on Imports (2006–2009)



What on earth can the U.S. do? China produces about 97 percent of the world's rare-earth oxides. The overwhelming U.S. source, the Mountain Pass mine in California, was closed in 2002. Molycorp Minerals will reestablish volume production there in 2012, but neither Molycorp nor other U.S. companies will have the facilities needed to refine the oxides into useful products; rebuilding that supply chain could take up to 15 years, according to the U.S. Government Accountability Office.

Import Sources (2006-2009)
Could come from a country's stockpile or recycling instead of current production



SOURCE: MINERAL COMMODITY SUMMARIES 2011, U.S. DEPARTMENT OF THE INTERIOR AND USGS

Graphic by Jen Christiansen