SUPERSTOCK

Moving on up. Genes show that some Hindu women could marry men of higher castes.

ences among Hindu castes, this study is one of the first to show the impact of social rules on the genome. "It is one of the clearest applications of molecular genetics to an anthropological question about mate choice and population substructuring," says Rebecca Cann, an evolutionary biologist at the University of Hawaii, Manoa. The work offers genetic proof that "humans choose mates according to certain rules … [which are often] different for men and women."

In their study, Jorde, University of Utah pediatric geneticist Michael Bamshad, and research specialist Scott Watkins worked with anthropologists Bhaskara Rao and J. M. Naidu of Andhra University in Vishakhapatnam, India. The team collected blood samples from 300 unrelated men from 12 populations spanning the Hindu caste hierarchy and set up a molecular genetics lab at Andhra University.

The researchers compared the DNA sequences of men of different castes, measuring how many differences there were in the same 400-base-pair segment of mtDNA and in seven markers, or segments, of their Y chromosomes. The mtDNA showed a slight blurring of caste lines. Men in closely ranked castes had similarities in their maternally inherited mtDNA, but there were few similarities between the mtDNA of men in the highest castes, such as Brahmins, and those in the lowest castes. "The genetic distances between upper and lower castes are much greater than [those] between upper and middle castes and [between] middle and lower castes," says Jorde. This gradient means, says Jorde, that these men's maternal ancestors had moved between adjacent ranks, mixing the genes between closely related castes. And historical records and strict social rules make it clear that women must have moved up, rather than down. "You get this ladder effect, where women tend to move to a caste of the next higher rank but [don't make] dramatic leaps from the lower castes to the very highest," says Jorde.

The distribution of markers on the Y chromosome showed a very different pattern. Men in the highest castes didn't share any more genetic markers with men in middle castes than they did with men in lower castes, suggesting little crossing of caste lines. In other words, "the men are stuck," says Jorde. The study confirms a pattern found in cultures worldwide—that women can move up in social rank, because higher ranking males will marry lower ranking females, but that low-ranking males have the least choice in mates, notes molecular anthropologist Mark Stoneking of Pennsylvania State University, University Park.

The study also gives the geneticists confidence that they can detect historical and social events in the genome. The effects of caste were still evident even though the system was outlawed in the 1960s. And the study shows an Asian origin for people in most castes, but the DNA of people in the upper castes has some similarities to that of Caucasians, which fits historical records that say the caste system was imposed by Caucasians sweeping in from the northwest. "It should make us optimistic about the power of genetic studies to reveal history," says Jorde.

–Ann Gibbons

PLANETARY SCIENCE

Fiery Io Models Earth's First Days

HOUSTON—To planetary geologists, the closest thing in the solar system to biblical fire and brimstone can be found on Jupiter's moon Io. Scorching eruptions pit the sulfur-laden surface of Io, which is the most volcanically active body known. Now this planetary hell has gotten even hotter. Using sophisticated instruments aboard the Galileo spacecraft orbiting Jupiter, researchers observed a surface temperature of about 1800 kelvins at the site of a particularly powerful eruption, they reported last month at the annual Lunar and Planetary Science Conference here.

"This is probably the highest temperature volcanism ever seen anywhere," says planetary geologist Ashley Davies of the Jet Propulsion Laboratory (JPL) in Pasadena, California. "It's really exciting," because such high temperatures imply a sort of volcanism that has not been common on Earth for billions of years. "We can use Io as a volcanological laboratory to test our models of terrestrial volcanism," Davies adds.

Io's behavior has made it the oddball of the solar system since the two Voyager spacecraft flew by in 1979. Thanks to Jupiter's gravitational kneading, Io burns with unusually hot inner fires, evidenced in Voyager images of umbrella plumes of sulfur dioxide shooting hundreds of kilometers above volcanic calderas. And the rest of Io's surface looked odd too, coated with sulfur of various pale yellow hues. Researchers assumed that lavas of elemental sulfur at about 700 K were reshaping the surface.

By the mid-1980s, increasingly sophisticated infrared observations from ground-based telescopes observed surface temperatures on Io as high as 1450 K—too hot for sulfur, which melts at much lower temperatures. That suggested basaltic lavas enriched in iron and magnesium, which melt at higher temperatures and are similar to the magmas that feed Earth's midocean ridges.

NASA/JPL

The devil's playground. A new volcanic hot spot at Pillan Patera produced record high temperatures and spewed dark debris (circular deposits, upper right) over an area the size of Arizona.

Now Io's perceived temperature has taken yet another jump. Planetary scientists Alfred McEwen and Laszlo Keszthelyi of the University of Arizona in Tucson and their colleagues reported at the meeting that Galileo's Solid State Imaging instrument recorded hot spots, including the caldera Pillan Patera, that reach temperatures in excess of 1600 K and probably as high as 2000 K. The Near-Infrared Mapping Spectrometer on Galileo confirmed a temperature for Pillan of 1825 K, reported Davies. About 30 hot spots—many of which are associated with sulfur dioxide plumes—glow in the infrared at temperatures greater than 1000 K, McEwen reported.

"Something very hot and very vigorous is going on" at Io's volcanic hot spots, says Davies. He envisions fiercely hot magma glowing through cracks in a thin solid crust atop churning lava lakes, lobes of flowing lava breaking out from encrusted volcanic material, or even lava spouting like a fountain from a rift. Whatever form the eruptions take, the magma is like nothing seen on Earth for a long time, says planetary scientist Dennis Matson of JPL. The temperatures of basaltic magma top out at 1500 K, so Io's magmas are probably ultramafic—so rich in magnesium and iron that their melting points approach 2000 K, he says.

Because an ultramafic composition is the result of repeated cycling that concentrates magnesium and iron, this fits planetary scientists' latest view of Io as the scene of the most intense geological processing in the solar system. Jupiter has driven enough heat through the moon to melt every bit of it 40 times over, estimate Keszthelyi and McEwen. To find a time on Earth that was in any way comparable, "you're looking at a period before continents formed," says Matson, a time that is not preserved in Earth's geologic record. The Earth of more than 3.8 billion years ago would still have been hot from its formation and heated further by frequent comet and asteroid impacts. It may have been destroying and recycling its crust so rapidly—as Io appears to be doing now—that continents couldn't form.

Scientists using Io to understand the mysteries of the early Earth will get a windfall if Galileo makes its first really close pass by Io, scheduled for October 1999. Assuming Jupiter's fierce radiation belts haven't killed or crippled the spacecraft by then (*Science*, 13 March, p. 1628), planetary geologists will get a good look inside the gates of hell.

–Richard A. Kerr

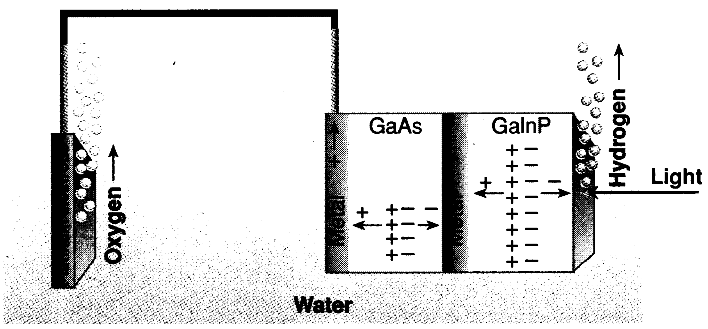
RENEWABLE ENERGY

A Record in Converting Photons to Fuel

It's the ultimate in clean energy: Generate fuel from water using only the power of sunlight, and when the fuel burns, it gives off nothing but water. Outlandish as it sounds, the dream was accomplished decades ago by using solar energy to split water into its components, oxygen and hydrogen—a powerful fuel that can be used to run everything from power plants to cars. But as a commercial proposition, the process has been a nonstarter because it's so inefficient and expensive. The two steps involved—generating electricity from sunlight and using it to split water—normally take place in separate devices, and energy is lost in between.

Now on page 425, researchers at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, have come up with a single device that accomplishes both tasks and has set a world record in efficiency for converting photons to fuel. The new solar-powered water splitter, built by NREL chemists John Turner and Oscar Khaselev, converts about 12.5% of the energy in sunlight to gaseous fuel—nearly double the previous record achieved by a conventional two-step process.

SOURCE: KHASELEV *ET AL.*



Solar water splitter. Two different semiconductors produce electrical charges with just the right energies to catalyze the split.

Marye Anne Fox, a chemist at the University of Texas, Austin, calls this efficiency "impressive." Fox's UT colleague Adam Heller adds that the new device avoids one pitfall common to conventional solar water splitters: It doesn't require the additional external energy that others need to get the job done. The NREL device "is a stand-alone cell that is nicely efficient and no longer needs external energy," says Heller. "It's a nice milestone." Even so, it's not about to catalyze a wholesale switch from fossil fuels to hydrogen, because the semiconductors at the heart of the new devices are expensive; they are currently used only for specialized applications, such as powering satellites.

Splitting water to create gaseous hydrogen and oxygen is quite simple. Stick a pair of metal electrodes into water, apply a voltage across them, and presto, oxygen gas is liberated at one electrode and hydrogen gas at the other. The process, known as electrolysis, is commonly used to produce pure hydrogen for making everything from food oils to computer chips. But it's expensive and requires fossil fuels to generate the electricity that powers the process. So energy researchers have long dreamed of using solar energy to drive the electrolysis.

The basic principle of generating electricity from sunlight is, again, well known. When photons from sunlight strike normally static electrons in some semiconductor materials, they kick the electrons into a higher energy level, allowing them to roam about. Left behind are electron vacancies, or "holes," that act like positive charges that can also migrate through the material. Additional semiconductor layers on either side of the absorbing layer then channel the electrons and holes in opposite directions, creating an electric current that can perform work or be stored in a battery. But, unfortunately, combining this so-called photovoltaic effect with electrolysis in a single device isn't simple.

First, there's a compatibility problem. Solar cells must sit in water in order to split it into hydrogen and oxygen, but semiconductors that are efficient light absorbers are often unstable in water. Then there's the energy problem. A water molecule splits into hydrogen and oxygen atoms only if each atom absorbs electrical charges packing very precise—and different—amounts of energy. In conventional electrolysis, the metal electrodes carry electrical charges with a wide energy range, allowing those with just the right amount of energy to catalyze the split. But semiconductors are more finicky. Charges in these materials can exist only at well-defined energy levels, and "nature has not been kind to us in this instance," says Turner. The only semiconductor materials that produce electrical charges at just the right levels to generate both hydrogen and oxygen are very poor absorbers of sunlight.

To overcome these problems, Turner and Khaselev constructed a sandwichlike device that pairs the talents of two different semiconductor materials. One—made from gallium indium phosphide—absorbs ultraviolet and visible light and produces mobile electrons with the right energy to produce hydrogen. The other—made from gallium arsenide—absorbs infrared light and produces holes with the right amount of energy to produce oxygen. Gallium indium phosphide is stable in water, so it can be used directly as an electrode. But the unstable gallium arsenide layer is sealed with a transparent epoxy coating to protect it, and the holes are shuttled to a separate platinum electrode.

Although the new device appears to be efficient and stable, Turner estimates that it would produce hydrogen at three times the cost of the cheapest method for bulk production of hydrogen, in which hydrogen atoms are stripped from natural gas by superheated steam. Turner and his colleagues are now trying to engineer cheaper semiconductors to perform the water-splitting reaction. If they succeed, the energy of the future may finally find its way to the present.

–Robert F. Service