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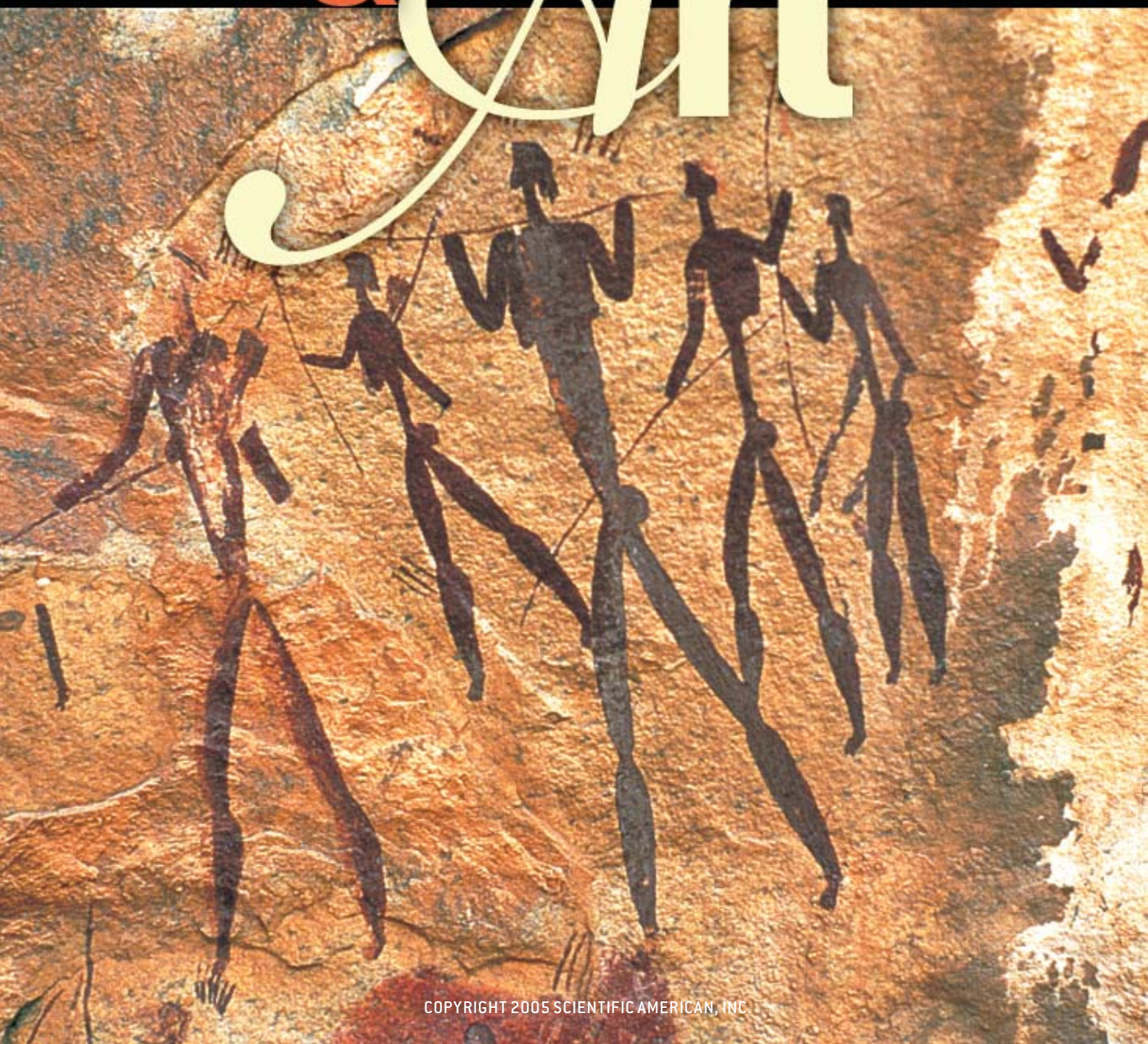
Science & Art



Scientific American may be best known for its coverage of such disciplines as astronomy and biotechnology, but as longtime readers can attest, the magazine has a tradition of examining cultural phenomena as well. It is in this spirit that we have put together a collection of articles exploring the intersection of science and art.

In this exclusive online issue, leading scientists share their expertise on what science can reveal about art—and vice versa. Discover the rock art of southern Africa, some of which dates back to more than 20,000 years ago, offering archaeologists unique insights into the minds of prehistoric humans. Tour the spectacularly decorated tomb of Nefertari, favorite wife of the Egyptian pharaoh Ramses II, which experts have taken great pains to conserve for future study—and public enjoyment. And learn how beautifully engraved wooden tablets hung under the roofs of religious buildings in Japan record a flourishing of native mathematics during the country's period of seclusion from the West.

Art, it is often said, imitates life, and can thus provide a window on society. It can also reveal much about the brain. Studies suggest that a number of great artists have been afflicted with madness and that there exists a link between creativity and mood disorders. Likewise, studies of how the blind sketch their surroundings indicate that touch and vision are closely tied. Two articles in this issue explore those relationships.—*The Editors*

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Rock Art in Southern Africa

Paintings and engravings made by ancestors of the San peoples encode the history and culture of a society thousands of years old

By Anne Solomon

originally published in November 1996

For more than three hours, a colleague and I walked through the grassy foothills of the Drakensberg Mountains in KwaZulu-Natal, meeting not a soul on the way. Ultimately, we came to a wide cave half-screened by bushes and a splashing waterfall. Behind this watery veil are some of the finest specimens of ancient San, or "Bushman," rock painting in South Africa. The water has not damaged them, although vandals have. We gazed at walls covered with more than 1,600 images of humans and animals engaged in myriad activities. That night, we slept in the cave, continuing our trip the next day.

That expedition, 10 years ago, was to obtain paint samples that might be radiocarbon-dated. One sample, from a painting of an eland (the biggest of all antelopes), contained microscopic quantities of organic material that allowed the image to be dated to about 400 years ago. Such a direct measurement is rare. Most pieces of rock art, painted in red, brown or yellow ocher—a hydrous iron oxide—contain no organic carbon. So radiocarbon dating, which measures the steady decline of the isotope carbon 14 in organic materials, cannot be used. Our earliest date comes from a Namibian cave, where excavated floors contained painted slabs between 19,000 and 26,000 years old. The oldest date we have for painting on cave walls indicates that mural art was being made at least 3,600 years ago.

Rock paintings and engravings, testimony to a once ubiquitous hunter-gatherer presence, are found from coast to coast in thousands of diverse sites in southern Africa. Some sites are sheltering sandstone caves with hundreds of images; others contain only one or two figures. Some paintings look exquisite, their lines and colors still fresh. Others are faint and crumbling, damaged by time, water and the graffiti of unthinking visitors.

By far the most common subjects in rock art are humans—usually shown in profile, sometimes unclothed—and a wide variety of animals. The most revered of the animals are the larger herbivores. The eland is widely celebrated, although different areas have their own favorites: the elephant in South Africa's Cape Province, for example, and a species of antelope called kudu in Zimbabwe. A variety of other creatures are also pictured. Snakes, lions and fish are not uncommon in the art of the Drakensberg Mountains. Hippopotamuses, rhinoceroses, rhebok, baboons, ostriches and domesticated animals appear in the art of many areas. Rarer themes include the aardwolf, aardvark and other creatures both real and imaginary. With the exception of snakes and bees, the San people rarely painted reptiles and insects.

Rock art research is among the most demanding of archaeology's subdisciplines. Without recourse to conventional archaeological methods—weighing, measuring, mapping and statistical comparison—rock art research relies on theoretically and culturally informed interpretations, supported by particularly rigorous argument. We do know that the artists were among the earliest inhabitants of southern Africa, the ancestors of the modern-day San peoples. The term "San" is a linguistic label: the

San and Khoekhoe—formerly Hottentot—languages make up the Khoisan group of many related languages and dialects, characterized by click sounds. The plant-gathering and hunting economy of the San has been extensively studied as a model for how people lived until relatively recent times, when animals and plants were domesticated.

Although rock art occasionally provides historical information, paintings and petroglyphs are not historical documents. It is only after the 15th century, when Europeans "discovered" southern Africa, that we begin to have a clearer picture of historical conditions. In 1652 the Dutch established the first permanent settlement in Cape Town. As the newcomers expanded their domain over the next three centuries, they frequently displaced indigenous peoples, whose traditional ways of life changed or disappeared entirely. In some areas, theft of cattle and horses by the San led to retaliatory raids by European farmers. Episodes are recorded in which entire San groups were massacred. Survivors of these communities were eventually absorbed into indigenous herding and farming societies or became laborers around European settlements.

The ancient art traditions had ceased by the 20th century. Today relatively few San speakers live in the old ways, except in parts of Botswana and Namibia. Only the wide distribution of archaeological sites, place-names and rock art alerts us to the vast areas once occupied by these peoples.

In studying the art, the archaeologist is forced to seek all imaginable clues. There are two classes of work: the paintings, which usually occur in caves and shallow shelters, and incised boulders and other surfaces that are found in the dry interior. The petroglyphs, which tend to be less figurative, have until recently attracted less attention than the paintings.

The style and, to a lesser extent, the subject matter of the paintings vary between regions. Often a single site includes works in several styles, so that it is impossible to tell whether it is the work of different artists or art from different historical periods. Early researchers suggested that simpler or less delicate images, in one color only, are the oldest, with color range and stylistic intricacy evolving through time. Today we know there is no such straightforward correlation. Some of the less accomplished work is probably the most recent—some perhaps made by shepherds and children.

Devotees have been trying to interpret rock art for more than a century. Those interpretations change with new knowledge, discoveries and intellectual currents. San testimonies would be extremely helpful in guiding us, but unfortunately, only one exists. It came from a Lesotho San man named Qing, who acted as a guide to a British official, Joseph Orpen, in the Lesotho Mountains in 1873. Qing was familiar with the making of rock paintings and commented on the paintings that they saw. Qing confirmed what some already suspected: that rock painting, as one contemporary European scholar wrote, was not "the mere daubing of figures for idle pastime" but "a truly artistic conception of the ideas which most deeply moved the Bushman mind."

In addition to Qing's direct testimony, researchers also draw on indirect accounts from San speakers. By far the richest body of material was collected a century ago, from people speaking a San language known as /Xam (the initial character is a click sound). In 1870 a group of /Xam San men from northern Cape Province were imprisoned in Cape Town for offenses ranging from stock theft to murder. Wilhelm H. I. Bleek, a German philologist, acquired custody of the men, who built huts at the bottom of his garden and worked as domestic servants. But their main task was sharing accounts of their traditions. While Bleek focused on the language, his sister-in-law, Lucy C. Lloyd, recorded thousands of pages of /Xam lore. A selection was published in *Specimens of Bushman Folklore,* written by W.H.I. Bleek and L. C. Lloyd (George Allen,

ROCK ART is found all over southern Africa. Its range attests to the vast areas once occupied by the ancient San. (Except as noted, all the paintings that follow are from KwaZulu-Natal.)

LUCY READING-IKKANDA

Dancing into the Night

DANCING, accompanied by clapping and singing in melodic overtones, is an integral part of San life. Women may dance alone, as in the painting *(left)*; a few are depicted with leather "aprons" that are still occasionally worn. The detail (*right*) from another painting of a dance probably depicts a female initiation ceremony.

London, 1911).

This extraordinary colonial encounter revealed the /Xam world: personal histories, myths, religious beliefs, and magical and mundane practices.

THERIANTHROPE (a half-animal, half-human figure) derives from San religious tradition. In the beginning, animals were humans; only after a creation event were they differentiated. This creature seems to be carrying a smaller antelope on its back.

ANNE SOLOMON

Although by the late 19th century these people no longer practiced rock art, their commentaries have proved extremely valuable for interpreting it. Together with Qing's account, the /Xam testimonies have helped show that African rock art is much more than mere decoration or reflections of everyday concerns. Instead rock art can best be understood as a religious art, reflecting the /Xam people's relations with the spirit world and to ritual practices. And almost certainly the act of painting itself had magical importance.

A comparison of Qing's account with the /Xam testimonies shows broad similarities between /Xam and Lesotho San myths. Both San peoples esteemed a creator figure named /Kaggen. Both also spoke of underwater beings and of the creation of the eland. Qing supplied the long-sought link between rock art and myth, whereas the /Xam accounts provided crucial cultural detail that Qing's commentary lacked. Researchers since have relied heavily on both sources.

Window on Culture

SEVERAL SCHOLARS have noted the extraordinary similarities between the mythology of San groups far distant from one another in time and space. All San peoples tell of a primeval time when animals were people; after an initial creation event, they were differentiated. But these first people were often stupid, lacking customs and manners, and only after a second creation did they become real people.

Many stories recount the doings of these animal people. Some explain the origins of fire, heavenly bodies and other physical phenomena. We hear why the baboon has a hairless rump, why people marry and why death is inevitable. Other narrative themes include encounters with warlike neighbors or dangerous carnivores. Food is a constant preoccupation, with a surprising number of stories featuring autophagy—the eating of one's own body. The stories dramatize the dilemmas of existence that faced San hunter-gatherers and emphasize themes involving death and regeneration.

THE AUTHOR

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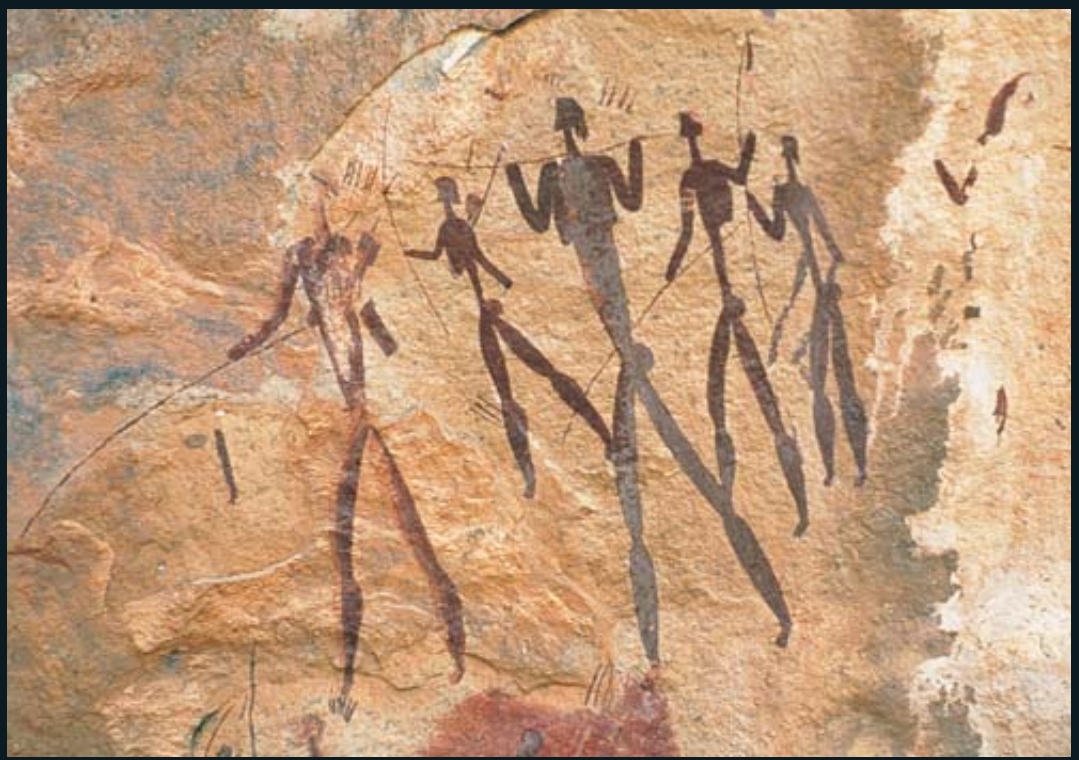


HUMANS are represented in varying styles. The men carrying quivers of arrows on their backs shown here (*top*) are exceedingly tall and thin, whereas the women are voluptuous (*below left*). The clothed figures (*below right*), wearing leather cloaks known as karosses, have strange concave faces.

The belief that animals were once people allows an interpretation of therianthropes—figures both human and animal. Some of these paintings, and others of fantastic creatures, may portray beings from the primordial world. Alternatively, some researchers contend that they depict the shaman's experience of physical transformation during a trance—when shamans enter the realm of the spirits of the dead.

Some experts, notably David Lewis-Williams and his colleagues at the University of the Witwatersrand, Johannesburg, have correctly observed that the art does not illustrate the mythology. They propose instead that rock art is connected to ritual—and to one ritual in particular: a healing dance that is still practiced by communities in Botswana and Namibia (these peoples do not make rock art). During a ritual dance that may last all night, shamans enter an altered state of consciousness induced by rhythmic movement, singing and clapping. In this hallucinatory state, they believe that they travel to the spirit realm to battle supernatural forces that cause illness.

Lewis-Williams and his associates have proposed that shamanic hallucinations may have prompted the first making of art, in Africa and elsewhere.

ANNE SOLOMON

Mysterious Engravings

ENGRAVINGS are found in arid areas, and the choice of subjects is puzzling. The boulder from northern Cape Province in South Africa, depicts antelopes. (Near its top left are sticklike figures of a European couple, probably added later.)

ANNE SOLOMON

They hypothesize that because humans all share the same neurological circuitry, visual hallucinatory forms should be similar throughout time—and that geometric designs drawn in the European Paleolithic and Bronze ages, as well as North American Indian art, may also be understood in terms of the healing trance dance and shamanic hallucinatory experiences.

It is certainly true that many creatures in San mythology are not portrayed in the rock art. Yet mythology does provide a crucial context for understanding ritual. Myths tell of the origin of death and disease, the trials of life that ritual practices address. Art-making can probably best be seen as being linked to ritual practices—such as rainmaking and initiation—recorded from recent San peoples.

Rainmakers

RECENT STUDIES have shown that hunting scenes in rock art are not as common as early researchers believed. Some paintings originally thought to depict hunts almost certainly portray rainmaking. Testimonies from the /Xam show that they viewed the rain cloud as an animal walking the countryside on "legs" of streaming rain. Rainmakers had to lead a large herbivore from its home in a water hole, take it to a high place and slaughter it; where its blood ran, rain would fall. The rain animals depicted in rock art resemble large herbivores, such as cattle, hippos or antelopes, but often with strange features and proportions. The rain bull in myths and stories embodied the lethal thunderstorm, whereas the female rain animals brought gentle rain.

Qing, in Lesotho, also described rainmaking. He described one rock painting as depicting underwater beings who tamed "eland and snakes." This painting shows six humanlike figures and two bristly animals of no known species, one led by a thong attached to its nose, the other being approached by two men with spears. Despite their geographic separation, both Qing and the /Xam described markedly similar beliefs regarding rain.

Some have argued that rainmakers depicted in such paintings were living shamans, but there is ample evidence that they were in fact considered to be benevolent spirits—dead family members who helped their living kin. Qing, for example, described antelope-headed men in rock paintings as "men who had died and now lived in rivers." These men, as well as the underwater beings leading the rain animals, can best be interpreted as spirits of the dead. /Xam commentators specifically stated that "sorcerers of rain" were dead people, as were "game sorcerers" to whom the living would appeal for help in the quest for food.

Understanding San beliefs about rain is crucial to understanding their art. Like Kalahari peoples today, the San told of two important beings, a creator figure and a master of death and disease. In the /Xam narratives, this death deity is the Rain Bull. He is the dangerous thunderstorm and the water in the waterhole. People became stars after they died, which then fell into the water where the Rain Bull lived. Qing's accounts of dead people living underwater derive from this same complex of beliefs.

Clearly, rock art images of people catching a rain animal allude to more than just controlling the weather. As master of the spirit world, the Rain Bull controls not just rain but also life and death, sickness and health. The "rain paintings" common in rock art can therefore be linked to people's efforts to prevent disease and misfortune and not just storms or drought.

Importance of Initiation

HUNTER-GATHERER societies such as the San are egalitarian, with both

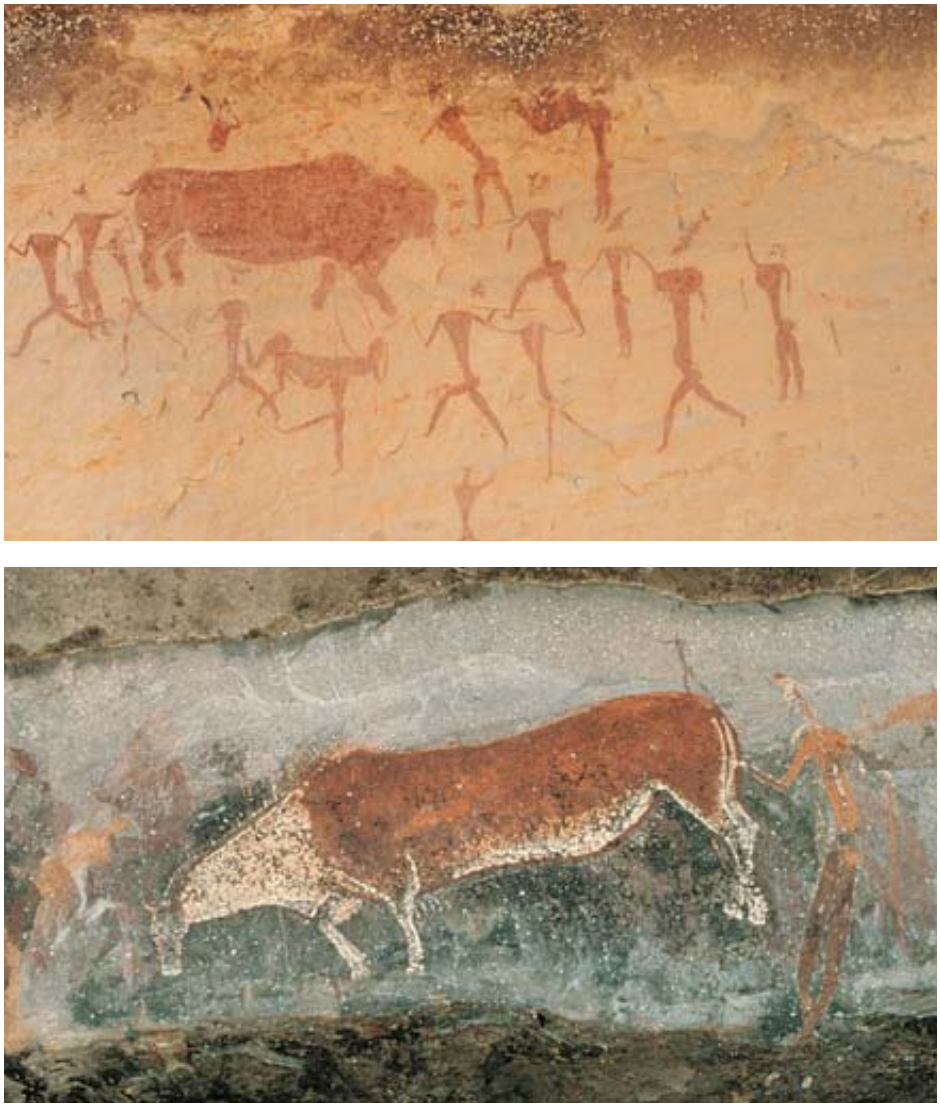
sexes having equal access to resources. Nevertheless, social distinctions do exist, and the two most important in these societies—gender and age—meet in the institution of initiation. Ceremonies for girls at puberty, copiously documented, seem to eclipse male initiation, which seems at most to have been a lesser celebration of a boy's first kill. Contemporary Kalahari hunter-gatherers also have conspicuous female initiations. Numerous /Xam stories tell of female initiates who disobeyed the puberty seclusion rules, sneaked off, and were then abducted and drowned by the Rain Bull. (After entering the cultural repertoire, the Rain Bull and other visual images may have been used in varied contexts for different purposes. Initiation paintings, for example, do not seem to involve interactions with the spirit world.)

/Xam initiation stories tell of the dangers attractive female initiates posed to men. The purpose of the rites, however, was probably equally to protect young women from inappropriate male attention. In the close proximity of band societies, members are highly dependent on social cooperation and harmony. Tensions between kin arising from sexual jealousies and misdemeanors may be socially and economically destructive. A purpose of initiation was surely to regulate interpersonal behavior and avoid such conflicts.

Though not abundant, some rock art sites and compositions may have been part of gender-specific initiation rites. Hugely voluptuous female figures with genital details, brandishing crescent-shaped objects, may well relate to female initiation. Paintings of women's dances may be linked to initiation or birth. A remote shelter high in the southwestern Cape Province mountains—unusual for its abundance of female figures and total absence of male imagery—may also pertain to female initiation or birth. Another composition apparently depicting a female initiation ceremony is found in a KwaZulu-Natal Drakensberg site. It shows a prone figure and three clapping women in a circular enclosure. Other figures dance outside. On the periphery of the composition (not shown in the illustration) is a male figure with considerably overemphasized genitalia.

Many sites contain a profusion of diverse imagery, different in theme and style. Some may have been used over centuries for a variety of purposes, others only once or twice, for a particular end. Recent interpretations have emphasized healing of the sick, an action only rarely rendered explicitly in rock art. However, some images previously thought to depict rain animals may be of the Rain Bull himself. Because he is the death figure, these images may have been painted in an effort to cure physical illnesses.

Of course, paintings and engravings depicting European colonists, wagons, soldiers and domestic animals may well be records of real events rather than ritual occasions. In addition, some rock art appears to reflect interactions between the San and other groups. John E. Parkington and his collegues at the University of Cape Town have suggested that handprints found along the southwestern coast, usually overlying earlier art, may have been the work of Khoi herders. Depictions of cattle introduced by the migrating herders and farmers, as well as iron artifacts, maize cobs and glass beads found in excavations, all testify



PROBABLE RAIN CEREMONY, showing an animal being captured by rainmakers (*top*), is painted in red ocher. The eland (*bottom*) is the southern San creator's favorite animal—and, along with other large herbivores, is associated with rain.

ANNE SOLOMON

Rocky Bestiary

ANNE SOLOMON

DIVERSE ANIMALS occur in San art. Some rain animals resemble a hippopotamus (*top*); this one is from Zimbabwe. The delicate rhebok (*bottom*) is a game animal. The painting actually contains two rheboks, superposed. (The second rhebok has its head downward.) Humans and large herbivores are believed to possess *n/ow,* a quality linked to birth, death and weather: good *n/ow* brings rain, whereas bad *n/ow* is associated with harsh conditions. The San's preference for portraying humans and large herbivores may have to do with their possessing *n/ow.*

to San involvement in other African economies.

New Interpretations

THE FINAL IMAGES themselves may not be alone in creating significance to the prehistoric artists. The act of painting itself may also have been important. Recent research in anthropology and art history has drawn attention to the process of art making and of the materials used, as opposed to creating an end product for viewing (as is usual in Western arts). This may be especially relevant to understanding San arts.

Probably each step of the painting process in San art carried cultural significance. One indigenous account from 1910 mentions ritual preparations that involved pigments being ground by women at full moon. In my research, I have emphasized the symbolic and spiritual significance of technically nonessential substances, such as fat and eland blood, that were said to be added to the paint mixture, presumably as magical aids. The act of making art, it appears, exerted magical effects that could influence the spirits and help control fate.

Powerful analytical techniques are now available for identifying these paint ingredients and culture-specific "recipes" of ancient paintings. This information would not only help us understand the significance of rock art but is also of interest for reasons ranging from resource exploitation to ancient trade to contemporary conservation.

I have researched the use of pigments and paints, with a view to identifying "magical" additives. This work, with the assistance of soil scientists at the University of KwaZulu-Natal, has involved a suite of techniques, including x-ray fluorescence (to provide quantitative data on minor and trace element composition), x-ray diffraction (to reveal crystal structure and parent rock types of paint ingredients), and environmental scanning electron microscopy (to yield qualitative data on elements present). Another promising technique that we have used experimentally is synchrotron radiation analysis. This technique, suitable for tiny samples, allows for x-ray fluorescence and x-ray diffraction of the same spot. So far these sophisticated research tools have generated more questions and problems than answers. The variability in both pigments and paints may be too vast to produce results relevant to answering archaeological questions.

The function and many meanings of rock art in history and prehistory still generate debate, although a broadly spiritual role is now well established. As an extraordinary and evocative record of the past, San rock art is becoming part of the culture of postapartheid South Africa. Yet paintings face many threats. Through the combined efforts of a spectrum of specialists, we hope to ensure that the rock art will endure as a testament to an ancient African culture, tragically displaced. SA

MORE TO EXPLORE

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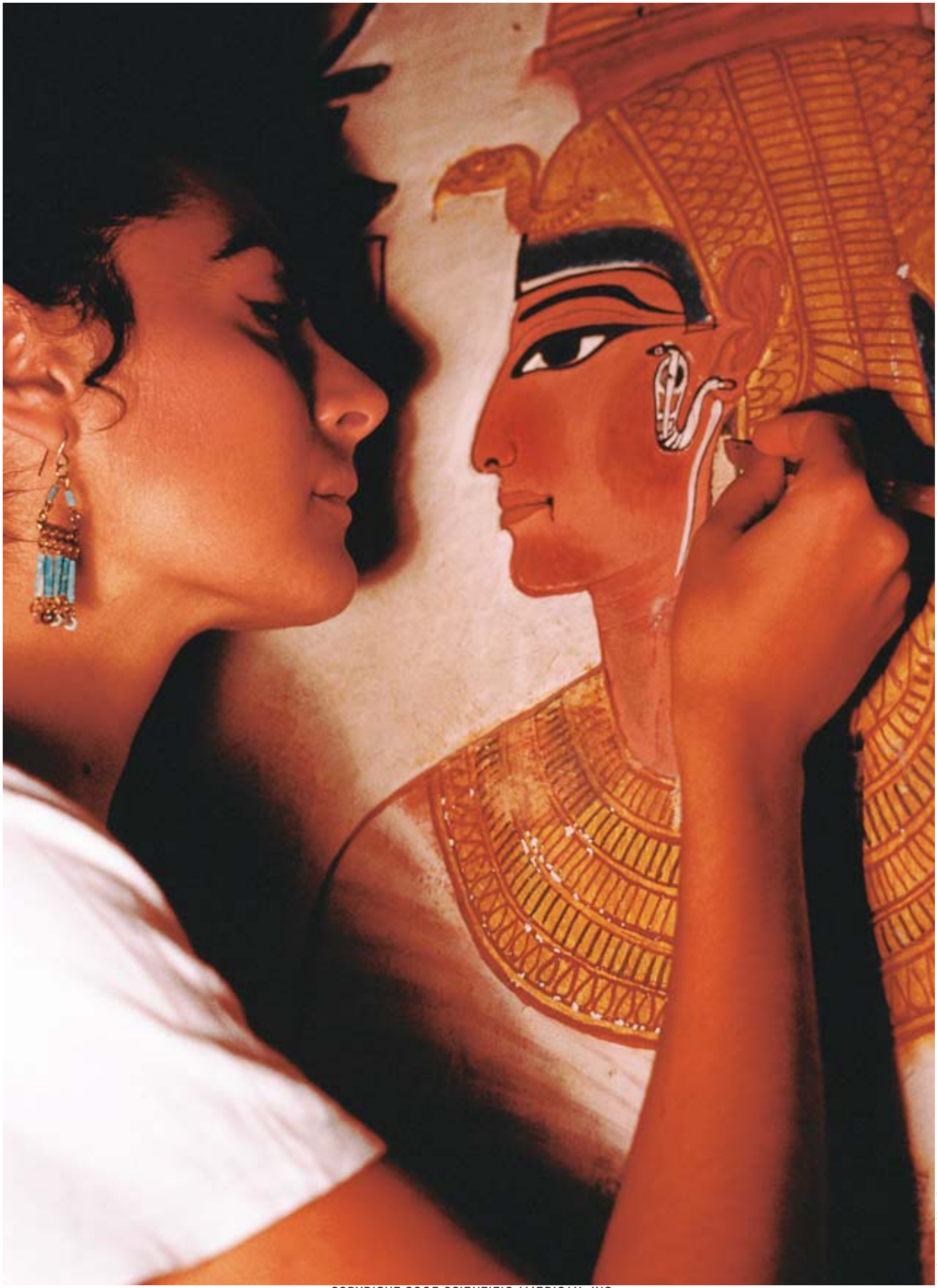


G. ALDANA *J. Paul Getty Trust*

The tomb of this ancient Egyptian queen is testament to the great love of Pharaoh Ramses II. Its preservation is testament to advances in conservation

Preserving Nefertari's Legacy

by Neville Agnew and Shin Maekawa

originally published in October 1999

Little is known about Nefertari, favorite wife of Ramses II, the pharaoh who ruled Egypt from about 1290 to 1224 B.C. But it is clear she was beloved by her husband. He ensured that the statue dedicated jointly to Nefertari and the goddess Hathor at Abu Simbel was on the same scale as his, an honor no other Egyptian queen achieved. His names for Nefertari bespoke great love as well: "lady of charm," "sweet of love," "beautiful of face," "for whom the sun shines." And after her death, Ramses II bestowed on Nefertari a final, spectacular tribute: even though she was not of royal lineage, he buried her in a decorated tomb in the Valley of the Queens.

G. ALDANA J. Paul Getty Trust

The wall paintings in Nefertari's tomb are among the most beautiful of all pharaonic funerary art. As in other tombs, the images of Nefertari are solely about her journey to the afterlife and her encounters with Osiris and Isis, among other deities; no paintings depict her everyday life with Ramses II or her six or seven children. But even as they describe a ritualized journey—following a strict formula laid out in the 174 or so chapters of the Egyptian Book of the Dead—the paintings in Nefertari's tomb are unique in their vivid color and detail and richness.

Ramses II's devotion to his queen may have protected her as she moved into the afterlife, but it could not protect her as she moved through the ages. When Italian archaeologist Ernesto Schiaparelli discovered the tomb in 1904, it had already been broken into and looted. The treasures that were to accompany Nefertari in her death were gone, her sarcophagus smashed and her mummy spirited away.

The tomb's wall paintings were severely disturbed as well, but this was the result of natural processes, not of grave robbers. Salt had leached from the limestone bedrock into which the tomb was carved and had crystallized below the painted plaster, destroying a large proportion of the paintings. Over the next decades, visitors to the spectacular tomb inadvertently accelerated this deterioration: the main culprit was most probably their incessant touching of the fragile surfaces, but moisture from their breath and sweat may have contributed as well. Archaeologists and art historians became increasingly concerned, and in the 1920s the Metropolitan Museum of Art in New York City sponsored extensive photographic documentation of the murals. (This record supplemented 132 glass plate negatives that Schiaparelli's photographer had assiduously made in 1904 and 1905, as well as other photographic records that had been made in the intervening years.) But the paintings remained in danger; finally, they were so obviously imperiled that the Egyptian government closed the tomb to the public in the late 1930s.

Nefertari's lovely legacy then sat in dusty silence, visited only by a few scholars. Beginning in the late 1970s, several groups—including the United Nations Educational, Scientific and Cultural Organization (UNESCO), the International Center for the Study of Preservation and the Restoration of Cultural Property, and Cairo University—conducted a series of studies about the condition of various important tombs. The research brought to light, again, the deplorable state of the Nefertari wall paintings and ultimately led conservators at the Getty Conservation Institute and the Egyptian Antiquities Organization to propose saving the remaining paintings—and potentially reopening the tomb to the public.

Between 1986 and 1992 the two organizations conserved the paintings, employing advanced tools and techniques. The

PAST AND PRESENT come face to face as conservator Lorenza D'Alessandro examines a painting of Queen Nefertari (*previous page*), assessing how best to save it. As its colorful entrance reveals, the tomb of Nefertari in the Valley of the Queens contains some of the most spectacular paintings of its era (*above*).

SALT CRYSTALS, which formed as water infiltrated the limestone into which the tomb was carved, forced the plaster away from the bedrock and destroyed a large proportion of the paintings before the conservators began their work (*above, top*). Earlier efforts at restoration had tried, unsuccessfully, to stem the damage by holding the plaster in place with gauze (*above, bottom*). This time the approach was thorough: conservators removed the salt crystals, reattached the plaster to the walls and cleaned the paintings (*right*).

project combined the skills of art historians, conservationists, Egyptologists, environmental scientists, topographers, chemists, technicians and other specialists. It was not only a matter of protecting the wall paintings—a challenging enough task—but the microclimate and hydrological conditions of the entire tomb had to be understood and addressed so that the destruction would not start anew once the work was finished.

Now, seven years after completion, it is apparent that the paintings are stable and that the project is an enduring success. Visitors are once again able to see the marvelous images and to admire the serene beauty of Queen Nefertari. And they know they are looking at originals, not at the work of 20th-century hands. The team that labored on the undertaking agreed from the outset that no restoration would be done. In other words, no paint would be applied where it had been lost—despite the fact that the photographic records could have permitted such restoration.

The restoration of works of art is sometimes done, even if reluctantly, to re-create the original visual harmony and consistency of a piece. This process, however, inevitably compromises the integrity of the object. In the case of Nefertari's tomb—a site of great antiquity—everyone involved decided that the wall paintings should show evidence of the passage of time and that the ancient should not be hybridized with the modern.

Assessing the Damage

The team began the conservation process by evaluating the overall condition of the paintings. They studied every inch of plaster to see where it had fallen off, whether it was holding together or holding to the wall, and whether it had cracked; they also looked for places where rock fragments were jutting through the plaster. They examined the paint to

PHOTOGRAPHS BY G. ALDANA *J. Paul Getty Trust*

see whether it was flaking, being abraded or losing its cohesiveness and whether it was covered with dirt, dust or insect nests. At the same time, the team recorded the extent of the salt crystallization on the surface of the paintings and between the rock face and the plaster. Finally, they located the earlier interventions: the places where paintings had been retouched, holes patched, and facing—such as gauze or adhesive tape—applied.

Once the condition survey was finished, Paolo Mora, former chief conservator of the Central Institute of Restoration in Rome, and his wife, Laura Mora, began the laborious work of conserving the paintings. The Moras and their colleagues started by taking minute pigment samples from the paintings as well as samples of the plaster underneath. Because of sophisticated machines and techniques—including x-ray diffraction, x-ray fluorescence, polarizing light microscopy, and gas and liquid chromatography—the scientists needed only the tiniest of samples to determine the chemical composition of the materials. Once the ingredients were known, the researchers could figure out how best to save or stabilize the ancient paintings. In the interim, they prevented further degradation by applying strips of Japanese mulberry bark paper to the plaster, which kept it from falling off the walls and which could be easily removed once they were ready to begin work.

They discovered that the pigments were, not surprisingly, typical of Nefertari's time: Egyptian green; Egyptian blue (or cuprorivaite); red from iron oxide, with a trace of manganese and arsenic; ocher for yellow; calcite, anhydrite and huntite for white; and charcoal for black. The binding medium—which holds the pigments together—was largely gum arabic, a natural resin from a local acacia tree. The workers also found that some of the paintings had been varnished with tree resin and egg white—although two modern synthetic resins showed up as well in lab analyses, suggesting that there

had been some earlier, undocumented restoration effort. The plaster was composed of gypsum, anhydrite and Nile silt, with some crushed limestone mixed in; wheat straw had been used to reinforce it and to prevent it from cracking as it dried.

Once they knew what they were dealing with, the team members could set about the work. For 469 days—spread over five years—they cleaned paintings, removed salt crystals from rock faces and in places underneath the plaster, and then reattached the plaster to the bedrock using an acrylic adhesive mixed with local sand and gypsum powder. They reattached flakes of paint and in places where the binding medium had degraded added a compound called acrylic copolymer to prevent it from breaking down further. They filled in holes with lime mortar and removed old, badly done repairs.

It was critically important that these efforts not affect the original colors. So before they even started any of this conservation work, Michael Schilling of the Getty Conservation Institute made 1,500 color measurements at 160 locations throughout the tomb. He used a chromometer (in this case, a Minolta CR-121) to assess exact hue. These records not only helped to guide the process by demonstrating that no shift in the color had occurred but also will aid ongoing monitoring of the paintings.

Keeping the Salt Out

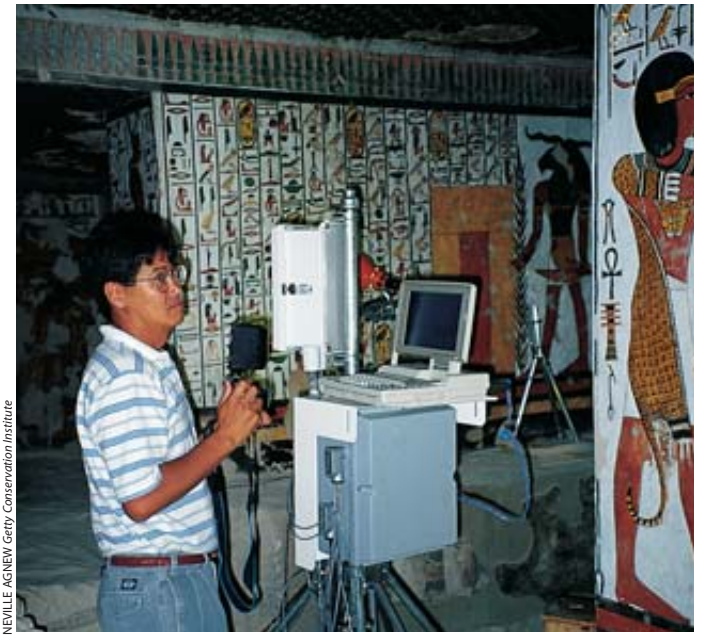
Concern about the future of these paintings centers on the most obvious threat: salt. When work began on the tomb, thick, 15-millimeter (0.6-inch) layers of salt were discovered under the plaster, forcing it from the wall. The salt came from Theban limestone, the marine sediment into which the tomb was cut. Salt is not a worry in most tombs, because the extremely dry Egyptian climate serves as a powerful preservative, keeping mummies and their artifacts sere and intact. But the site of Nefertari's tomb had some source of water that dissolved the salt and made it mobile.

Not everyone who has worked on the project agrees—even today, after years of study—about where exactly the water came from. Some was clearly introduced in the wet plaster applied by Ramses's wall painters themselves. That moisture, however, would not have caused thick layers of crystals to form. A more probable explanation is the very occasional, but very heavy, rain that falls about every 50 years on average. Many of the tombs in the region, including those in the Valley of the Kings, have flooded repeatedly since antiquity. Moisture infiltration is evident in Nefertari's tomb, especially at the entrance. It is likely that water seeped slowly through fissures, leaching salt from the bedrock as it traveled and leaving salt behind and on the painted surfaces as it evaporated from the walls.

To monitor humidity and temperature, one of us (Maekawa) recorded both the external climate and the microclimate of the tomb over several years and seasons. He found that the external temperature varied from a high of 40 degrees Celsius (104 degrees Fahrenheit) in the summer to 10 degrees C (50 degrees F) in the winter mornings; external humidity fluctuated wildly as well, from 80 percent in the winter to as low as 10 percent during the rest of the year. These outside conditions could affect the tomb because of leaks at the entrance, but for the most part, the internal temperature remained about 29 degrees C and humidity was stable at 50 percent. Maekawa also noted that there was natural ventilation during the winter: cooler air entered the tomb at floor level, forcing warmer air out through the entrance stairway. This movement caused the paintings and plaster to stay dry. When visitors entered the tomb, however, humidity rose sharply.

Maekawa had to take into account the fact that peak tourist season falls primarily during the summer—just when air is not circulating back outside and humidity could easily become trapped in the tomb. The more sweat and moisture in the tomb, the more likely it is that microflora, such as mold and bacteria, will grow on the surface of the paintings and destroy them and that salt crystals could begin to develop again.

In addition to monitoring temperature and humidity, Maeka-



NEVILLE AGNEW *Getty Conservation Institute*

SHIN MAEKAWA *Getty Conservation Institute*

ENVIRONMENTAL MONITORING is crucial to the future of the paintings. Shin Maekawa used a solar-powered system to study the microclimate of the tomb (*left*); he determined that the number of visitors had to be carefully regulated so that the temperature and humidity in the tomb did not catalyze the growth of salt crystals again. No more than 150 tourists are allowed in per day (*below*).

WALL PAINTINGS are now fully conserved, and the images of Queen Nefertari's voyage to the afterlife remain vibrant. Their continued survival depends on striking a careful balance between public access and protection of the paintings.

wa had to carefully track levels of carbon dioxide. Because the tomb's natural ventilation is poor, this gas does not move out of the tomb easily and can pose a health hazard for tourists. Carbon dioxide can also react with moisture in the air, producing carbonic acid, which can discolor the wall paintings. Maekawa found that ambient levels of 340 parts per million (ppm) surged to 2,500 ppm when tourists visited the tomb. For health reasons, levels should not get higher than 1,000 ppm.

Keeping these findings in mind, the Egyptian Antiquities Organization—now the Supreme Council of Antiquities—designed a system that would ostensibly protect the tomb and yet would allow visitors to see it. They installed lights that gave off very little heat. And they set up a ventilation system that extracts air from the tomb, allowing unfiltered, dry air from the outside to flow in and replace the humid air generated by the visitors. Since late 1995 a maximum of 150 people a day, in groups of 10 to 15, have been allowed in for no more than 15 minutes. (They pay $30 for the visit, a fee that has generated about $1.5 million each year for the Egyptian government.) To date, the only noticeable impact of the stream of visitors has been an influx of dust, which has settled on the paintings, obscuring them somewhat.

Despite this careful monitoring, the potential damage of these visitors needs to be considered carefully and periodically evaluated. Although people should be free to see the beautiful paintings, to experience the mystery and awe of this gate to our past, we must establish a balance—a difficult task that extends far beyond Nefertari's tomb to all other threatened archaeological sites. Because damage is irreversible and cumulative—and because we seem to be able to destroy in just a few decades what has survived for millennia—it may not be right for everyone to have the access they expect. After all, that is what Ramses II intended for his wife: a peaceful, sealed existence. SA

G. ALDANA J. Paul Getty Trust

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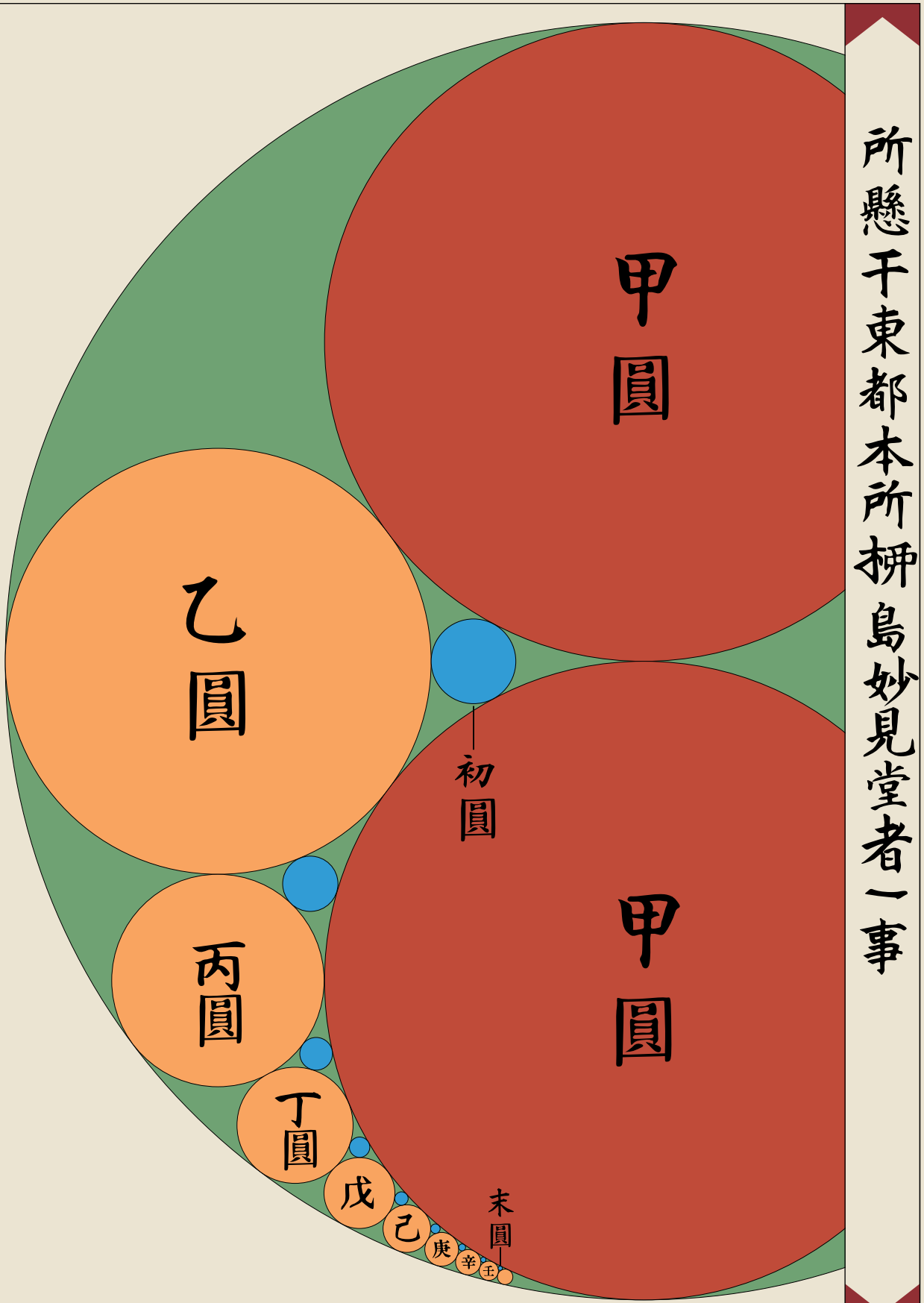

所懸干東都本所枡島妙見堂者一事

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Japanese Temple Geometry

During Japan's period of national seclusion (1639–1854), native mathematics thrived, as evidenced in sangaku*—wooden tablets engraved with geometry problems hung under the roofs of shrines and temples*

by Tony Rothman, with the cooperation of Hidetoshi Fukagawa

Of the world's countless customs and traditions, perhaps none is as elegant, nor as beautiful, as the tradition of *sangaku,* Japanese temple geometry. From 1639 to 1854, Japan lived in strict, self-imposed isolation from the West. Access to all forms of occidental culture was suppressed, and the influx of Western scientific ideas was effectively curtailed. During this period of seclusion, a kind of native mathematics flourished.

Devotees of math, evidently samurai, merchants and farmers, would solve a wide variety of geometry problems, inscribe their efforts in delicately colored wooden tablets and hang the works under the roofs of religious buildings. These *sangaku,* a word that literally means mathematical tablet, may have been acts of homage—a thanks to a guiding spirit—or they may have been brazen challenges to other worshipers: Solve this one if you can!

For the most part, *sangaku* deal with ordinary Euclidean geometry. But the problems are strikingly different from those found in a typical high school geometry course. Circles and ellipses play a far more prominent role than in Western problems: circles within ellipses, ellipses within circles. Some of the exercises are quite simple and could be solved by first-year students. Others are nearly impossible, and modern geometers invariably tackle them with advanced methods, including calculus and affine transformations. Although most of the problems would be classified today as recreational or educational mathematics, a few predate known Western results, such as the Malfatti theorem, the Casey theorem and the Soddy hexlet theorem. One problem reproduces the Descartes circle theorem. Many of the tablets are exceptionally beautiful and can be regarded as works of art.

Pleasing the *Kami*

It is natural to wonder who created the *sangaku* and when, but it is easier to ask such questions than to answer them. The custom of hanging tablets at shrines was established in Japan centuries before *sangaku* came into existence. Shintoism, Japan's native religion, is populated by "eight hundred myriads of gods," the *kami.* Because the *kami,* it was said, love horses, those worshipers who could not present a living horse as an offering to the shrine might instead give a likeness drawn on wood. As a result, many tablets dating from the 15th century and earlier depict horses.

Of the *sangaku* themselves, the oldest surviving tablet has been found in Tochigi Prefecture and dates from 1683. Another tablet, from Kyoto, is dated 1686, and a third is from 1691. The 19th-century travel diary of the mathematician Kazu Yamaguchi refers to an even earlier tablet—now lost—dated 1668. So historians guess that the custom first arose in the second half of the 17th century. In 1789 the first collection containing typical *sangaku* problems was published. Other collections followed throughout the 18th and 19th centuries. These books were either handwritten or printed with wooden blocks and are remarkably beautiful. Today more than 880 tablets survive, with references to hundreds of others in the various collections. From a survey of the extant *sangaku,* the tablets seem to have been distributed fairly uniformly throughout Japan, in both rural and urban districts, with about twice as many found in Shinto shrines as in Buddhist temples.

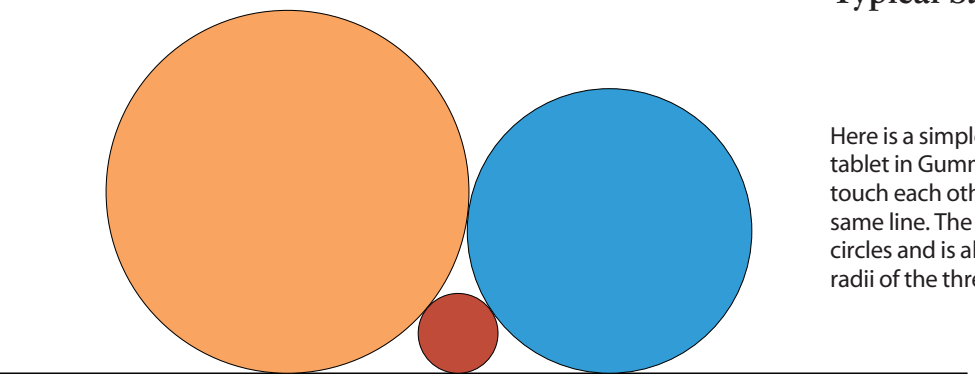
Most of the surviving *sangaku* contain more than one theorem and are frequently brightly colored. The proof of the theorem is usually not given, only the result. Other information typically includes the name of the presenter and the date. Not all the problems deal solely with geometry. Some ask for the volumes of various solids and thus require calculus. (This point raises the interesting question of what techniques the practitioners brought into play; some speculations will be offered in the following discussion.) Other tablets contain Diophantine problems—that is, algebraic equations requiring solutions in integers.

In modern times the *sangaku* have been largely forgotten but for a few devotees of traditional Japanese mathematics. Among them is Hidetoshi Fukagawa, a high school teacher in Aichi Prefecture, roughly halfway between Tokyo and Osaka. About 30 years ago Fukagawa decided to study the history of Japanese mathematics in hopes of finding better ways to teach his courses. A mention of the math tablets in an old library book greatly astonished him, for he had never heard of such a thing. Since then, Fukagawa, who holds a Ph.D. in mathematics, has traveled widely in Japan to study the tablets and has amassed a collection of books dealing not only

BRYAN CHRISTIE, AFTER TOSHIHISA IWASAKI

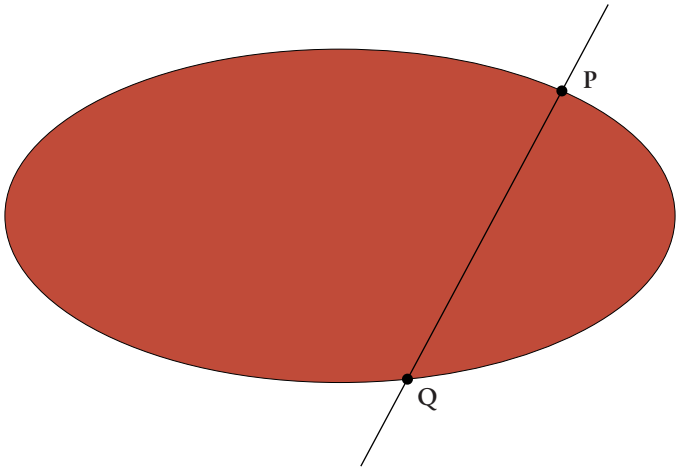
***SANGAKU* PROBLEMS typically involve multitudes of circles within circles or of spheres within other figures. This problem is from a *sangaku,* or mathematical wooden tablet, dated 1788 in Tokyo Prefecture. It asks for the radius of the *n*th largest blue circle in terms of *r,* the radius of the green circle. Note that the red circles are identical, each with radius *r*/2. (Hint: The radius of the fifth blue circle is *r*/95.) The original solution to this problem deploys the Japanese equivalent of the Descartes circle theorem.** **(The answer can be found on page 21.)**

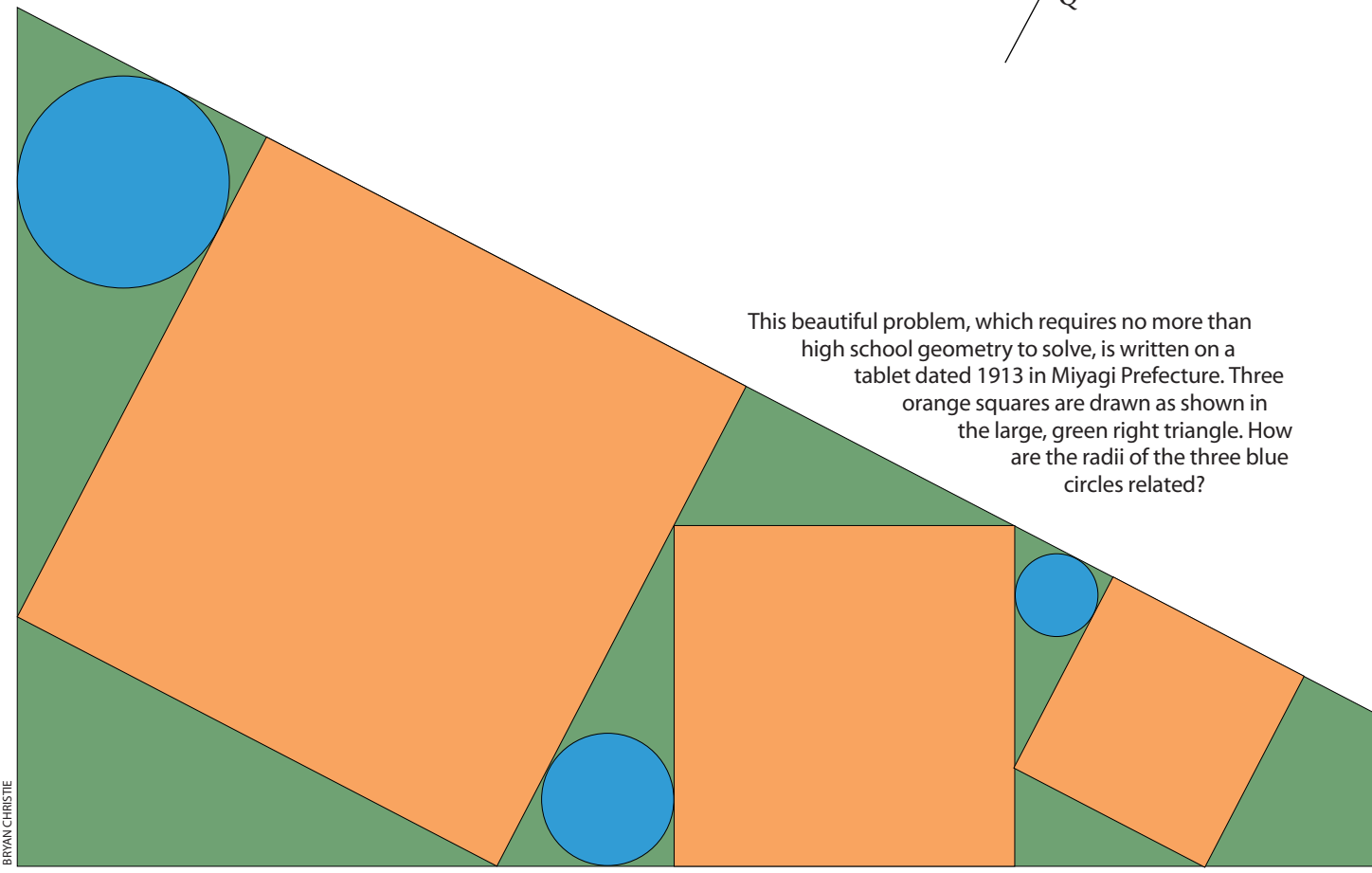
Typical *Sangaku* Problems*



Here is a simple problem that has survived on an 1824 tablet in Gumma Prefecture. The orange and blue circles touch each other at one point and are tangent to the same line. The small red circle touches both of the larger circles and is also tangent to the same line. How are the radii of the three circles related?

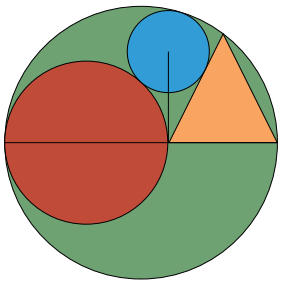
This striking problem was written in 1912 on a tablet extant in Miyagi Prefecture; the date of the problem itself is unknown. At a point P on an ellipse, draw the normal PQ such that it intersects the other side. Find the least value of PQ. At first glance, the problem appears to be trivial: the minimum PQ is the minor axis of the ellipse. Indeed, this is the solution if $b < a \leq \sqrt{2}b$, where a and b are the major and minor axes, respectively; however, the tablet does not give this solution but another, if $2b^2 < a^2$.



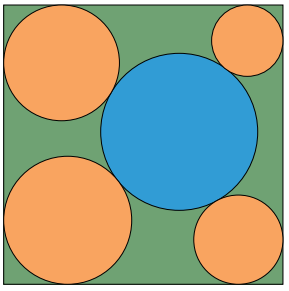


This beautiful problem, which requires no more than high school geometry to solve, is written on a tablet dated 1913 in Miyagi Prefecture. Three orange squares are drawn as shown in the large, green right triangle. How are the radii of the three blue circles related?

BRYAN CHRISTIE



In this problem, from an 1803 *sangaku* found in Gumma Prefecture, the base of an isosceles triangle sits on a diameter of the large green circle. This diameter also bisects the red circle, which is inscribed so that it just touches the inside of the green circle and one vertex of the triangle, as shown. The blue circle is inscribed so that it touches the outsides of both the red circle and the triangle, as well as the inside of the green circle. A line segment connects the center of the blue circle and the intersection point between the red circle and the triangle. Show that this line segment is perpendicular to the drawn diameter of the green circle.



This problem comes from an 1874 tablet in Gumma Prefecture. A large blue circle lies within a square. Four smaller orange circles, each with a different radius, touch the blue circle as well as the adjacent sides of the square. What is the relation between the radii of the four small circles and the length of the side of the square? (Hint: The problem can be solved by applying the Casey theorem, which describes the relation between four circles that are tangent to a fifth circle or to a straight line.)

*Answers are on page 21.

with *sangaku* but with the general field of traditional Japanese mathematics.

To carry out his research, Fukagawa had to teach himself *Kambun,* an archaic form of Japanese that is closely related to Chinese. *Kambun* is the Japanese equivalent of Latin; during the Edo period (1603–1867), scientific works were written in this language, and only a few people in modern Japan are able to read it fluently. As new tablets have been discovered, Fukagawa has been called in to decipher them. In 1989 Fukagawa, along with Daniel Pedoe, published the first collection of *sangaku* in English. Most of the geometry problems accompanying this article were drawn from that collection.

Wasan versus *Yosan*

Although the origin of the *sangaku* cannot be pinpointed, it can be localized. There is a word in Japanese, *wasan,* that is used to refer to native Japanese mathematics. *Wasan* is meant to stand in opposition to *yosan,* or Western mathematics. To understand how *wasan* came into existence—and with it the unusual *sangaku* problems—one must first appreciate the peculiar history of Japanese mathematics.

Of the earliest times, very little is definitely known about mathematics in Japan, except that a system of exponential notation, similar to that employed by Archimedes in the *Sand Reckoner,* had been developed. More concrete information dates only from the mid-sixth century A.D., when Buddhism—and, with it, Chinese mathematics—made its way to Japan. Judging from the works that were taught at official schools at the start of the eighth century, historians infer that Japan had imported the great Chinese classics on arithmetic, algebra and geometry.

According to tradition, the earliest of these is the *Chou-pei Suan-ching,* which contains an example of the Pythagorean theorem and the diagram commonly used to prove it. This part of the tome is at least as old as the sixth century B.C.

A more advanced state of knowledge is represented in the *Chiu-chang Suan-shu,* considered the most influential of Chinese books on mathematics. The *Chiu-chang* describes methods for finding the areas of triangles, quadrilaterals, circles and other figures. It also contains simple word problems of the type that torment many high school students today: "If five oxen and two sheep cost eight taels of gold, and two oxen and eight sheep cost eight taels, what is the price of each animal?" The dates of the *Chiu-chang* are also uncertain, but most of it was probably composed by the third century B.C. If this information is correct, the *Chiu-chang* contains perhaps the first known mention of negative numbers and an early statement of the quadratic equation. (According to some historians, the ancient Egyptians had begun studying quadratic equations centuries before, prior to 2000 B.C.)

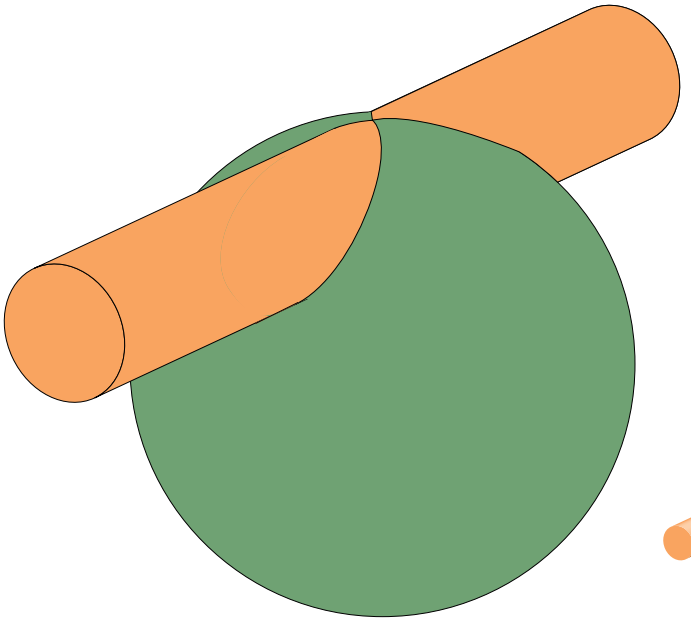
Despite the influx of Chinese learning, mathematics did not then take root in Japan. Instead the country entered a dark age, roughly contemporaneous with that of Western Europe. In the West, church and monastery became the centers of learning; in Japan, Buddhist temples served the same function, although mathematics does not seem to have played much of a role. By some accounts, during the Ashikaga shogunate (1338–1573) there could hardly be found in all Japan a person versed in the art of division.

It is not until the opening of the 17th century that definite historical records exist of any Japanese mathematicians. The first of these is Kambei Mori, who prospered around the year 1600. Although only one of Mori's works—a booklet—survives, he is known to have been instrumental in developing arithmetical calculations on the *soroban,* or Japanese abacus, and in popularizing it throughout the country.

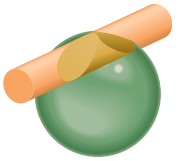
The oldest substantial Japanese work on mathematics actually extant belongs to Mori's pupil Koyu Yoshida (1598–1672). The book, entitled *Jinko-ki* (literally, "small and large numbers"), was published in 1627 and also concerns operations on the *soroban. Jinko-ki* was so influential that the name of the work often was synonymous with arithmetic. Because of the book's influence, computation—as opposed to logic—became the most important concept in traditional Japanese mathematics. To the extent that it makes sense to credit anyone with the founding of *wasan,* that honor probably goes to Mori and Yoshida.

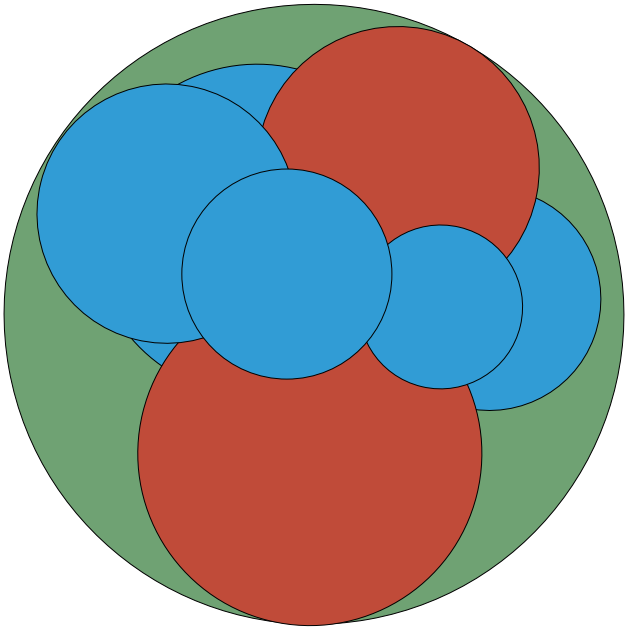
A Brilliant Flowering

Wasan, though, was created not so much by a few individuals but by something much larger. In 1639 the ruling Tokugawa shogunate (during the Edo period), to strengthen its power and diminish challenges to its reign, de-

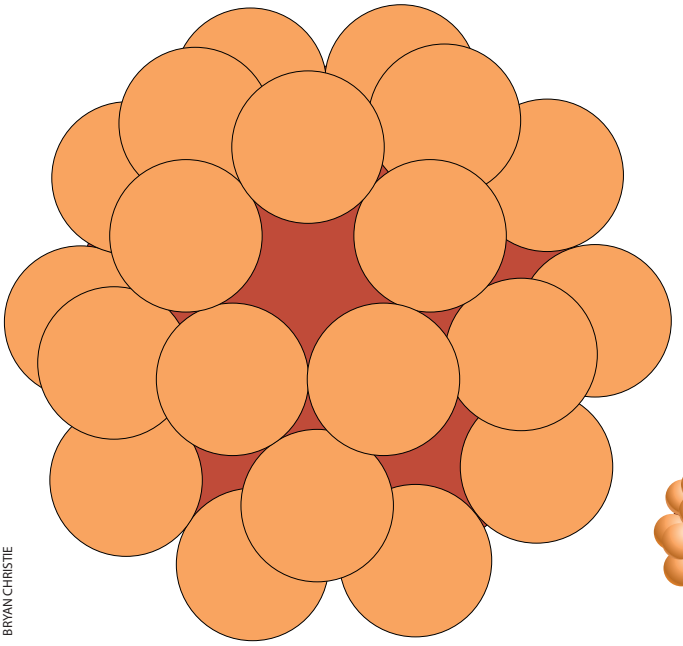


From a *sangaku* dated 1825, this problem was probably solved by using the *enri*, or the Japanese circle principle. A cylinder intersects a sphere so that the outside of the cylinder is tangent to the inside of the sphere. What is the surface area of the part of the cylinder contained inside the sphere? (The inset shows a three-dimensional view of the problem.)

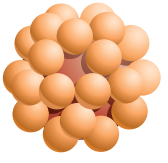




This problem is from an 1822 tablet in Kanagawa Prefecture. It predates by more than a century a theorem of Frederick Soddy, the famous British chemist who, along with Ernest Rutherford, discovered transmutation of the elements. Two red spheres touch each other and also touch the inside of the large green sphere. A loop of smaller, different-size blue spheres circle the "neck" between the red spheres. Each blue sphere in the "necklace" touches its nearest neighbors, and they all touch both the red spheres and the green sphere. How many blue spheres must there be? Also, how are the radii of the blue spheres related? (The inset shows a three-dimensional view of the problem.)



Hidetoshi Fukagawa was so fascinated with this problem, which dates from 1798, that he built a wooden model of it. Let a large sphere be surrounded by 30 small, identical spheres, each of which touches its four small-sphere neighbors as well as the large sphere. How is the radius of the large sphere related to that of the small spheres? (The inset shows a three-dimensional view of the problem.)



BRYAN CHRISTIE

*Answers are on page 21.

creed the official closing of Japan. During this time of *sakoku,* or national seclusion, the government banned foreign books and travel, persecuted Christians and forbade Portuguese and Spanish ships from coming ashore. Many of these strictures would remain for more than two centuries, until Commodore Matthew C. Perry, backed by a fleet of U.S. warships, forced the end of *sakoku* in 1854.

Yet the isolationist policy was not entirely negative. Indeed, during the late 17th century, Japanese art and culture flowered so brilliantly that those years go by the name of *Genroku,* for "renaissance." In that era, *haiku* developed into a fine art form; No and Kabuki theater reached the pinnacle of their development; *ukiyo-e,* or "floating world" pictures, originated; and tea ceremonies and flower arranging reached new heights. Neither was mathematics left behind, for *Genroku* was also the age of Kowa Seki.

By popular accounts, Seki (1642–1708) was Japan's Isaac Newton or Gottfried Wilhelm Leibniz, although this reputation is difficult to substantiate. If the numbers of manuscripts attributed to him are correct, then most of his work has been lost. Still, there is no question that Seki left many disciples who were influential in the further development of Japanese mathematics.

The first—and incontestable—achievement of Seki was his theory of determinants, which is more powerful than that of Leibniz and which antedates the German mathematician's work by at least a decade. Another accomplishment, more relevant to temple geometry but of debatable origin, is the development of methods for solving high-degree equations. (Much traditional Japanese mathematics from that era involves equations to hundreds of degrees; one such equation is of the 1,458th degree.) Yet a third accomplishment sometimes attributed to Seki, and one that might also bear on *sangaku,* is the development of the *enri,* or circle principle.

The *enri* was quite similar to the method of exhaustion developed by Eudoxus and Archimedes in ancient Greece for computing the area of circles. The main difference was that Eudoxus and Archimedes used *n*-sided polygons to approximate the circle, whereas the *enri* divided the circle into *n* rectangles. Thus, the limiting procedure was somewhat different. Nevertheless, the *enri* represented a crude form of integral calculus that was later extended to other figures, including spheres and ellipses. A type of differential calculus was also developed around the same period. It is conceivable that the *enri* and similar techniques were brought to bear on *sangaku.* Today's mathematicians would use modern calculus to solve these problems.

Spheres within Ellipsoids

During Seki's lifetime, the first books employing the *enri* were published, and the first *sangaku* evidently made their appearance. The dates are almost certainly not coincidental; the followers of Yoshida and Seki must have influenced the development of *wasan,* and, in turn, *wasan* may have influenced them. Fukagawa believes that Seki encountered *sangaku* on his way to the shogunate castle, where he was officially employed as court mathematician, and that the tablets pushed him to further researches. A legend? Perhaps. But by the next century, books were being published that contained typical native Japanese problems: circles within triangles, spheres within pyramids, ellipsoids surrounding spheres. The problems found in these books do not differ in any important way from those found on the tablets, and it is difficult to avoid the conclusion that the peculiar flavor of all *wasan* problems—including the *sangaku*—is a direct result of the policy of national seclusion.

But the question immediately arises: Was Japan's isolation complete? It is certain that apart from the Dutch who were allowed to remain in Nagasaki Harbor on Kyushu, the southernmost island, all Western traders were banned. Equally clear is that the Japanese themselves were severely restricted. The mere act of traveling abroad was considered high treason, punishable by death. It appears safe to assume that if the isolation was not complete, then it was most nearly so, and any foreign influence on Japanese mathematics would have been minimal.

The situation began to change in the 19th century, when the *wasan* gradually became supplanted by *yosan,* a process that produced hybrid manuscripts written in *Kambun* with Western mathematical notations. And, after the opening of Japan by Commodore Perry and the subsequent collapse of the Tokugawa shogunate in 1867, the new government abandoned the study of native mathematics in favor of *yosan.* Some practitioners, however, continued to hang tablets well into the 20th century. A few *sangaku* even date from the current decade. But almost all the problems from this century are plagiarisms.

The final and most intriguing question is, Who produced the *sangaku?* Were the theorems so beautifully drawn on wooden tablets the works of professional mathematicians or amateurs? The evidence is meager.

Only a handful of *sangaku* are mentioned in the standard *A History of Japanese Mathematics,* by David E. Smith and Yoshio Mikami. They cite the 1789 collection *Shimpeki Sampo,* or *Mathematical Problems Suspended before the Temple,* which was published by Kagen Fujita, a professional mathematician. Smith and Mikami mention a tablet on which the following was appended after the solution: "Feudal district of Kakegawa in Enshu Province, third month of 1795, Sonobei Keichi Miyajima, pupil of Sadasuke Fujita of the School of Seki." Mikami, in his *Development of Mathematics in China and Japan,* mentions the "Gion Temple Problem," which was suspended at the Gion Temple in Kyoto by Enkyu Tsuda, pupil of Enri Nishimura. Furthermore, the tablets were written in the specialized language of *Kambun,* signifying the mark of an educated class of practitioners.

From such scraps of information, it is tempting to conclude that the tablets were the work primarily of professional mathematicians and their students. Yet there are reasons to believe otherwise.

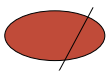
Many of the problems are elementary and can be solved in a few lines; they are not the kind of work a professional mathematician would publish. Fukagawa has found a tablet from Mie Prefecture inscribed with the name of a merchant. Others have names of women and children—12 to 14 years of age. Most, according to Fukagawa, were created by the members of the highly educated samurai class. A few were probably done by farmers; Fukagawa recalls how about 10 years ago he visited the former cottage of mathematician Sen Sakuma (1819–1896), who taught *wasan* to the farmers in nearby villages in Fukushima Prefecture. Sakuma had about 2,000 students.

Such instruction recalls the Edo period itself, when there were no colleges or universities in Japan. During that time, teaching was carried out at private schools or temples, where ordinary people would go to study reading, writ-

Answers to *Sangaku* Problems

Answer: $r/[(2n-1)^2+14]$. The original solution to this problem applies the Japanese version of the Descartes circle theorem several times. The answer given here was obtained by using the inversion method, which was unknown to the Japanese mathematicians of that era.

Answer: $1/\sqrt{r_3} = 1/\sqrt{r_1} + 1/\sqrt{r_2}$, where r_1, r_2 and r_3 are the radii of the orange, blue and red circles, respectively. The problem can be solved by applying the Pythagorean theorem.

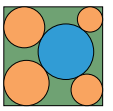


Answer: $\mathrm{PQ} = \dfrac{\sqrt{27}\,a^2b^2}{(a^2+b^2)^{3/2}}$

The problem can be solved by using analytic geometry to derive an equation for PQ and then taking the first derivative of the equation and setting it to zero to obtain the minimum value for PQ. It is not known whether the original authors resorted to calculus to solve this problem.

Answer: $r_2^2 = r_1 r_3$, where r_1, r_2 and r_3 are the radii of the large, medium and small blue circles, respectively. (In other words, r_2 is the geometric mean of r_1 and r_3.) The problem can be solved by first realizing that all the interior green triangles formed by the orange squares are similar. The original solution then looks at how the three squares are related.

Answer: In the original solution to this problem, the author draws a line segment that goes through the center of the blue circle and is perpendicular to the drawn diameter of the green circle. The author assumes that this line segment is different from the line segment described in the statement of the problem on page 87. Thus, the two line segments should intersect the drawn diameter at different locations. The author then shows that the distance between those locations must necessarily be equal to zero—that is, that the two line segments are identical, thereby proving the perpendicularity.

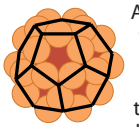


Answer: If a is the length of the square's side, and r_1, r_2, r_3 and r_4 are the radii of the upper right, upper left, lower left and lower right orange circles, respectively, then

$$a = \frac{2(r_1r_3 - r_2r_4) + \sqrt{2(r_1-r_2)(r_1-r_4)(r_3-r_2)(r_3-r_4)}}{r_1 - r_2 + r_3 - r_4}$$

Answer: $16t\sqrt{t(r-t)}$, where r and t are the radii of the sphere and cylinder, respectively.

Answer: Six spheres. The Soddy hexlet theorem states that there must be six and only six blue spheres (thus the word "hexlet"). Interestingly, the theorem is true regardless of the position of the first blue sphere around the neck. Another intriguing result is that the radii of the different blue spheres in the "necklace" (t_1 through t_6) are related by $1/t_1 + 1/t_4 = 1/t_2 + 1/t_5 = 1/t_3 + 1/t_6$.



Answer: $R = \sqrt{5}r$, where R and r are the radii of the large and small spheres, respectively. The problem can be solved by realizing that the center of each small sphere lies on the midpoint of the edge of a regular dodecahedron, a 12-sided solid with pentagonal faces.

BRYAN CHRISTIE

ing and the abacus. Because laypeople are more often drawn to problems of geometry than of algebra, it would not be surprising if the tablets were painted with such artistic care specifically to attract nonmathematicians.

The best answer, then, to the question of who created temple geometry seems to be: everybody. On learning of the *sangaku*, Fukagawa came to understand that, in those days, many of the Japanese loved and enjoyed math, as well as poetry and other art forms.

It is pleasant to realize that some *sangaku* were the works of ordinary mathematics devotees, carried away by the beauty of geometry. Perhaps a village teacher, after spending the day with students, or a samurai warrior, after sharpening his sword, would retire to his study, light an oil lamp and lose the world to an intricate problem involving spheres and ellipsoids. Perhaps he would spend days working on it in peaceful contemplation. After finally arriving at a solution, he might allow himself a short rest to savor the result of his hard labor. Convinced the proof was a worthy offering to his guiding spirits, he would have the theorem inscribed in wood, hang it in his local temple and begin to consider the next challenge. Visitors would notice the colorful tablet and admire its beauty. Many people would leave wondering how the author arrived at such a miraculous solution. Some might decide to give the problem a try or to study geometry so that the attempt could be made. A few might leave asking, "What if the problem were changed just so…."

Something for us all to consider. SA

The Author

TONY ROTHMAN received his Ph.D. in 1981 from the Center for Relativity at the University of Texas at Austin. He did postdoctoral work at Oxford, Moscow and Cape Town, and he has taught at Harvard University. Rothman has published six books, most recently *Instant Physics*. His next book is *Doubt and Certainty*, with E.C.G. Sudarshan, to be published this fall by Helix Books/Addison-Wesley. He has also recently written a novel about nuclear fusion. SCIENTIFIC AMERICAN wishes to acknowledge the help of Hidetoshi Fukagawa in preparing this manuscript. Fukagawa received a Ph.D. in mathematics from the Bulgarian Academy of Science. He is a high school teacher in Aichi Prefecture, Japan.

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Manic-Depressive Illness and Creativity

Does some fine madness plague great artists? Several studies now show that creativity and mood disorders are linked

by Kay Redfield Jamison

originally published in February 1995

The Author

KAY REDFIELD JAMISON is professor of psychiatry at the Johns Hopkins University School of Medicine. She wrote *Touched with Fire: Manic-Depressive Illness and the Artistic Temperament* and co-authored the medical text *Manic-Depressive Illness*. Jamison is a member of the National Advisory Council for Human Genome Research and clinical director of the Dana Consortium on the Genetic Basis of Manic-Depressive Illness. She has also written and produced a series of public television specials about manic-depressive illness and the arts.

"Men have called me mad," wrote Edgar Allan Poe, "but the question is not yet settled, whether madness is or is not the loftiest intelligence—whether much that is glorious—whether all that is profound—does not spring from disease of thought—from moods of mind exalted at the expense of the general intellect."

Many people have long shared Poe's suspicion that genius and insanity are entwined. Indeed, history holds countless examples of "that fine madness." Scores of influential 18th- and 19th-century poets, notably William Blake, Lord Byron and Alfred, Lord Tennyson, wrote about the extreme mood swings they endured. Modern American poets John Berryman, Randall Jarrell, Robert Lowell, Sylvia Plath, Theodore Roethke, Delmore Schwartz and Anne Sexton were all hospitalized for either mania or depression during their lives. And many painters and composers, among them Vincent van Gogh, Georgia O'Keeffe, Charles Mingus and Robert Schumann, have been similarly afflicted.

Judging by current diagnostic criteria, it seems that most of these artists—and many others besides—suffered from one of the major mood disorders, namely, manic-depressive illness or major depression. Both are fairly common, very treatable and yet frequently lethal diseases. Major depression induces intense melancholic spells, whereas manic-depression, a strongly genetic disease, pitches patients repeatedly from depressed to hyperactive and euphoric, or intensely irritable, states. In its milder form, termed cyclothymia, manic-depression causes pronounced but not totally debilitating changes in mood, behavior, sleep, thought patterns and energy levels. Advanced cases are marked by dramatic, cyclic shifts.

Could such disruptive diseases convey certain creative advantages? Many people find that proposition counterintuitive. Most manic-depressives do not possess extraordinary imagination, and most accomplished artists do not suffer from recurring mood swings. To assume, then, that such diseases usually promote artistic talent wrongly reinforces simplistic notions of the "mad genius." Worse yet, such a generalization trivializes a very serious medical condition and, to some degree, discredits individuality in the arts as well. It would be wrong to label anyone who is unusually accomplished, energetic, intense, moody or eccentric as manic-depressive. All the same, recent studies indicate that a high number of established artists—far more than could be expected by chance—meet the diagnostic criteria for manic-depression or major depression given in the fourth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-IV*). In fact, it seems that these diseases can sometimes enhance or otherwise contribute to creativity in some people.

By virtue of their prevalence alone, it is clear that mood disorders do not necessarily breed genius. Indeed, 1 percent of the general population suffer from manic-depression, also called bipolar disorder, and 5 percent from a major depression, or unipolar disorder, during their lifetime. Depression affects twice as many women as men and most often, but not always, strikes later in life. Bipolar disorder afflicts equal numbers of women and men, and more than a third of all cases surface before age 20. Some 60 to 80 percent of all adolescents and adults who commit suicide have a history of bipolar or unipolar illness. Before the late 1970s, when the drug lithium first became widely available, one person in five with manic-depression committed suicide.

Major depression in both unipolar and bipolar disorders manifests itself through apathy, lethargy, hopelessness, sleep disturbances, slowed physical movements and thinking, impaired memory and concentration, and a loss of pleasure in typically enjoyable events. The diagnostic criteria also include suicidal thinking, self-blame and inappropriate guilt. To distinguish clinical depression from normal periods of unhappiness, the common guidelines further require that these symptoms persist for a minimum of two to four weeks and also that they significantly interfere with a person's everyday functioning.

Mood Elevation

During episodes of mania or hypomania (mild mania), bipolar patients experience symptoms that are in many ways the opposite of those associated with depression. Their mood and self-esteem are elevated. They sleep less and have abundant energy; their productivity increases. Manics frequently become paranoid and irritable. Moreover, their speech is often rapid, excitable and intrusive, and their thoughts move quickly and fluidly from one topic to another. They usually hold tremendous conviction about the correctness and importance of their own ideas as well. This grandiosity can contribute to poor judgment and impulsive behavior.

Hypomanics and manics generally have chaotic personal and professional relationships. They may spend large sums of money, drive recklessly or pursue questionable business ventures or sexual liaisons. In some cases, manics suffer from violent agitation and delusional thoughts as well as visual and auditory hallucinations.

Rates of Mood Disorders

For years, scientists have documented some kind of connection between mania, depression and creative output. In the late 19th and early 20th centuries, researchers turned to accounts of mood disorders written by prominent artists, their physicians and friends. Although largely anecdotal, this work strongly suggested that renowned writers, artists and composers—and their first-degree relatives—were far more likely to experience mood disorders and to commit suicide than was the general population. During the past 20 years, more systematic studies of artistic populations have confirmed these findings. Diagnostic and psychological analyses of living writers and artists can give quite meaningful estimates of the rates and types of psychopathology they experience.

In the 1970s Nancy C. Andreasen of the University of Iowa completed the first of these rigorous studies, which made use of structured interviews, matched control groups and strict diagnostic criteria. She examined 30 creative writers and found an extraordinarily high occurrence of mood disorders and alcoholism among them. Eighty percent had experienced at least one episode of major depression, hypomania or mania; 43 percent reported a history of hypomania or mania. Also, the relatives of these writers, compared with the relatives of the control subjects, generally performed more creative work and more often had a mood disorder.

A few years later, while on sabbatical in England from the University of California at Los Angeles, I began a study of 47 distinguished British writers and visual artists. To select the group as best I could for creativity, I purposefully chose painters and sculptors who were Royal Academicians or Associates of the Royal Academy. All the playwrights had won the New York Drama Critics Award or the Evening Standard Drama (London Critics) Award, or both. Half of the poets were already represented in the *Oxford Book of Twentieth Century English Verse*. I found that 38 percent of these artists and writers had in fact been previously treated for a mood disorder; three fourths of those treated had required medication or hospitalization, or both. And half of the poets—the largest fraction from any one group—had needed such extensive care.

Hagop S. Akiskal of the University of California at San Diego, also affiliated with the University of Tennessee at Memphis, and his wife, Kareen Akiskal, subsequently interviewed 20 award-winning European writers, poets, painters and sculptors. Some two thirds of their subjects exhibited recurrent cyclothymic or hypomanic tendencies, and half had at one time suffered from a major depression. In collaboration with David H. Evans of the University of Memphis, the Akiskals noted the same trends among living blues musicians. More recently Stuart A. Montgomery and his wife, Deirdre B. Montgomery, of St. Mary's Hospital in London examined 50 modern British poets. One fourth met current diagnostic criteria for depression or manic-depression; suicide was six times more frequent in this community than in the general population.

Ruth L. Richards and her colleagues at Harvard University set up a system for assessing the degree of original thinking required to perform certain creative tasks. Then, rather than screening for mood disorders among those already deemed highly inventive, they attempted to rate creativity in a sample of manic-depressive patients. Based on their scale, they found that compared with individuals having no personal or family history of psychiatric disorders, manic-depressive and cyclothymic patients (as well as their unaffected relatives) showed greater creativity.

Biographical studies of earlier generations of artists and writers also show consistently high rates of suicide, depression and manic-depression—up to 18 times the rate of suicide seen in the general population, eight to 10 times that

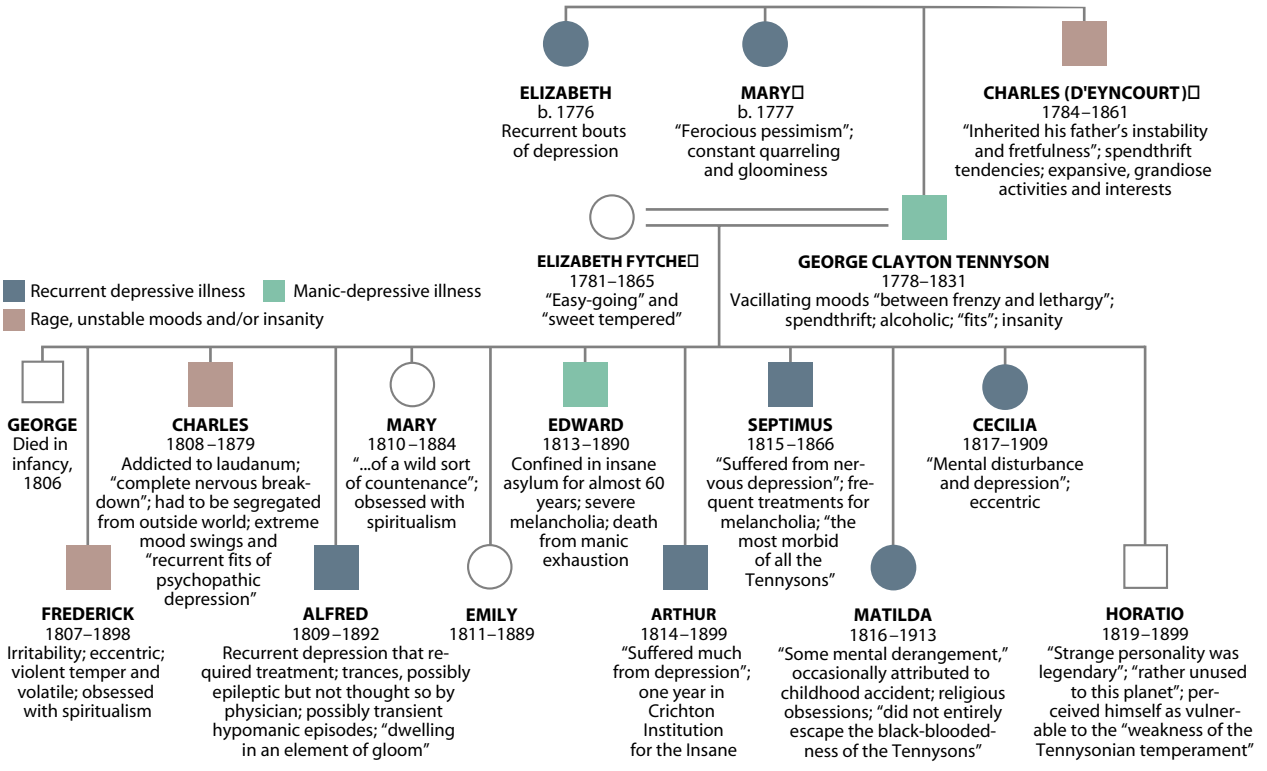
Highly creative indiviuals experience major mood disorders more often than do other groups in the general population.

The Tainted Blood of the Tennysons

Alfred, Lord Tennyson, who experienced recurrent, debilitating depressions and probable hypomanic spells, often expressed fear that he might inherit the madness, or "taint of blood," in his family. His father, grandfather, two of his great-grandfathers as well as five of his seven brothers suffered from insanity, melancholia, uncontrollable rage or what is today known as manic-depressive illness. His brother Edward was confined to an asylum for nearly 60 years before he died from manic exhaustion. Lionel Tennyson, one of Alfred's two sons, displayed a mercurial temperament, as did one of his three grandsons.

Modern medicine has confirmed that manic-depression and creativity tend to run in certain families. Studies of twins provide strong evidence for the heritability of manic-depressive illness. If an identical twin has manic-depressive illness, the other twin typically has a 70 to 100 percent chance of also having the disease; if the other twin is fraternal, the chances are considerably lower (approximately 20 percent). A review of pairs of identical twins reared apart from birth—in which at least one had been diagnosed as manic-depressive—found that in two thirds or more of the sets, the illness was present in both twins.

—K. R. J.



SOURCE: Adapted from Touched with Fire: Manic-Depressive Illness and the Artistic Temperament; *based on biographies, autobiographical writings and letters.*

LISA BURNETT

of depression and 10 to 20 times that of manic-depressive illness and its milder variants. Joseph J. Schildkraut and his co-workers at Harvard concluded that approximately half of the 15 20th-century abstract-expressionist artists they studied suffered from depressive or manic-depressive illness; the suicide rate in this group was at least 13 times the current U.S. national rate.

In 1992 Arnold M. Ludwig of the University of Kentucky published an extensive biographical survey of 1,005 famous 20th-century artists, writers and other professionals, some of whom had been in treatment for a mood disorder. He discovered that the artists and writers experienced two to three times the rate of psychosis, suicide attempts, mood disorders and substance abuse that comparably successful people in business, science and public life did. The poets in this sample had most often been manic or psychotic and hospitalized; they also proved to be some 18 times more likely to commit suicide than is the general public. In a comprehensive biographical study of 36 major British poets born between 1705 and 1805, I found similarly elevated rates of psychosis and severe psychopathology. These poets were 30 times more likely to have had manic-depressive illness than were their contemporaries, at least 20 times more likely to have been committed to an asylum and some five times more likely to have taken their own life.

These corroborative studies have confirmed that highly creative individuals experience major mood disorders more often than do other groups in the general population. But what does this mean for their work? How does a psychiatric illness contribute to creative achievement? First, the common features of hypomania seem highly conducive to original thinking; the diagnostic criteria for this phase of the disorder include "sharpened and unusually creative thinking and increased productivity." And accumulating evidence suggests that the cognitive styles associated with hypomania (expansive thought and grandiose moods) can lead to increased fluen-

cy and frequency of thoughts.

Mania and Creativity

Studying the speech of hypomanic patients has revealed that they tend to rhyme and use other sound associations, such as alliteration, far more often than do unaffected individuals. They also use idiosyncratic words nearly three times as often as do control subjects. Moreover, in specific drills, they can list synonyms or form other word associations much more rapidly than is considered normal. It seems, then, that both the quantity and quality of thoughts build during hypomania. This speed increase may range from a very mild quickening to complete psychotic incoherence. It is not yet clear what causes this qualitative change in mental processing. Nevertheless, this altered cognitive state may well facilitate the formation of unique ideas and associations.

People with manic-depressive illness and those who are creatively accomplished share certain noncognitive features: the ability to function well on a few hours of sleep, the focus needed to work intensively, bold and restless attitudes, and an ability to experience a profound depth and variety of emotions. The less dramatic daily aspects of manic-depression might also provide creative advantage to some individuals. The manic-depressive temperament is, in a biological sense, an alert, sensitive system that reacts strongly and swiftly. It responds to the world with a wide range of emotional, perceptual, intellectual, behavioral and energy changes. In a sense, depression is a view of the world through a dark glass, and mania is that seen through a kaleidoscope—often brilliant but fractured.

Where depression questions, ruminates and hesitates, mania answers with vigor and certainty. The constant transitions in and out of constricted and then expansive thoughts, subdued and then violent responses, grim and then ebullient moods, withdrawn and then outgoing stances, cold and then fiery states—and the rapidity and fluidity of moves through such contrasting experiences—can be painful and confusing. Ideally, though, such chaos in those able to transcend it or shape it to their will can provide a familiarity with transitions that is probably useful in artistic endeavors. This vantage readily accepts ambiguities and the counteracting forces in nature.

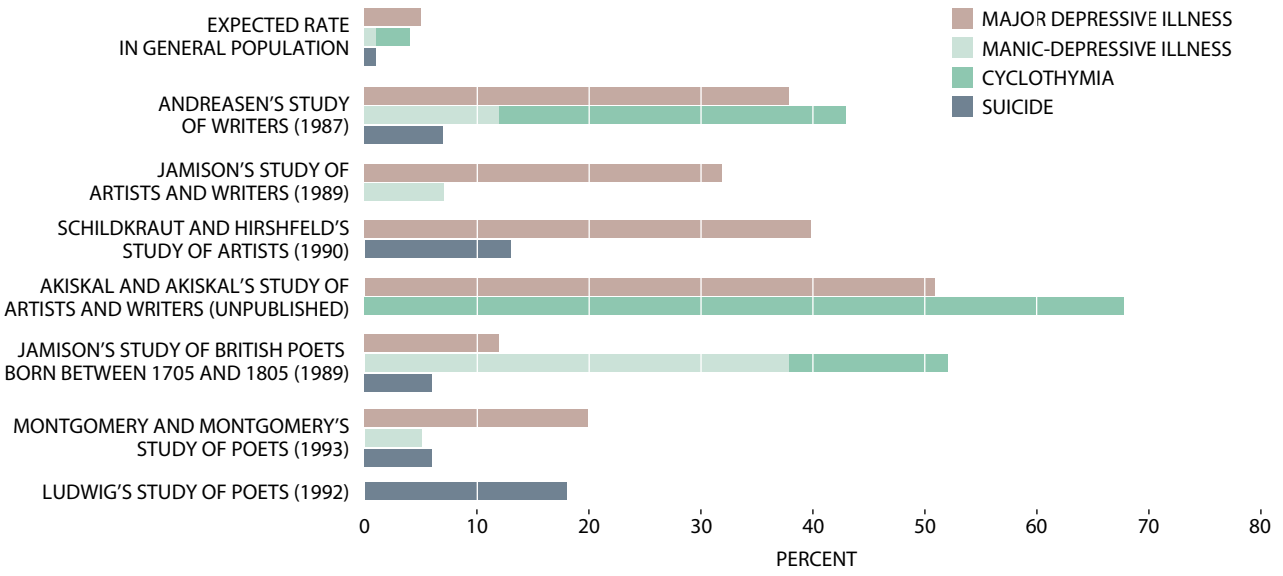
Extreme changes in mood exaggerate the normal tendency to have conflicting selves; the undulating, rhythmic and transitional moods and cognitive changes so characteristic of manic-depressive illness can blend or harness seemingly contradictory moods, observations and perceptions. Ultimately, these fluxes and yokings may reflect truth in humanity and nature more accurately than could a more fixed viewpoint. The "consistent attitude toward life" may not, as Byron scholar Jerome J. McGann of the University of Virginia points out, be as insightful as an ability to live with, and portray, constant change.

The ethical and societal implications of the association between mood disorders and creativity are important but poorly understood. Some treatment strategies pay insufficient heed to the benefits manic-depressive illness can bestow on some individuals. Certainly most

The Case of Vincent van Gogh

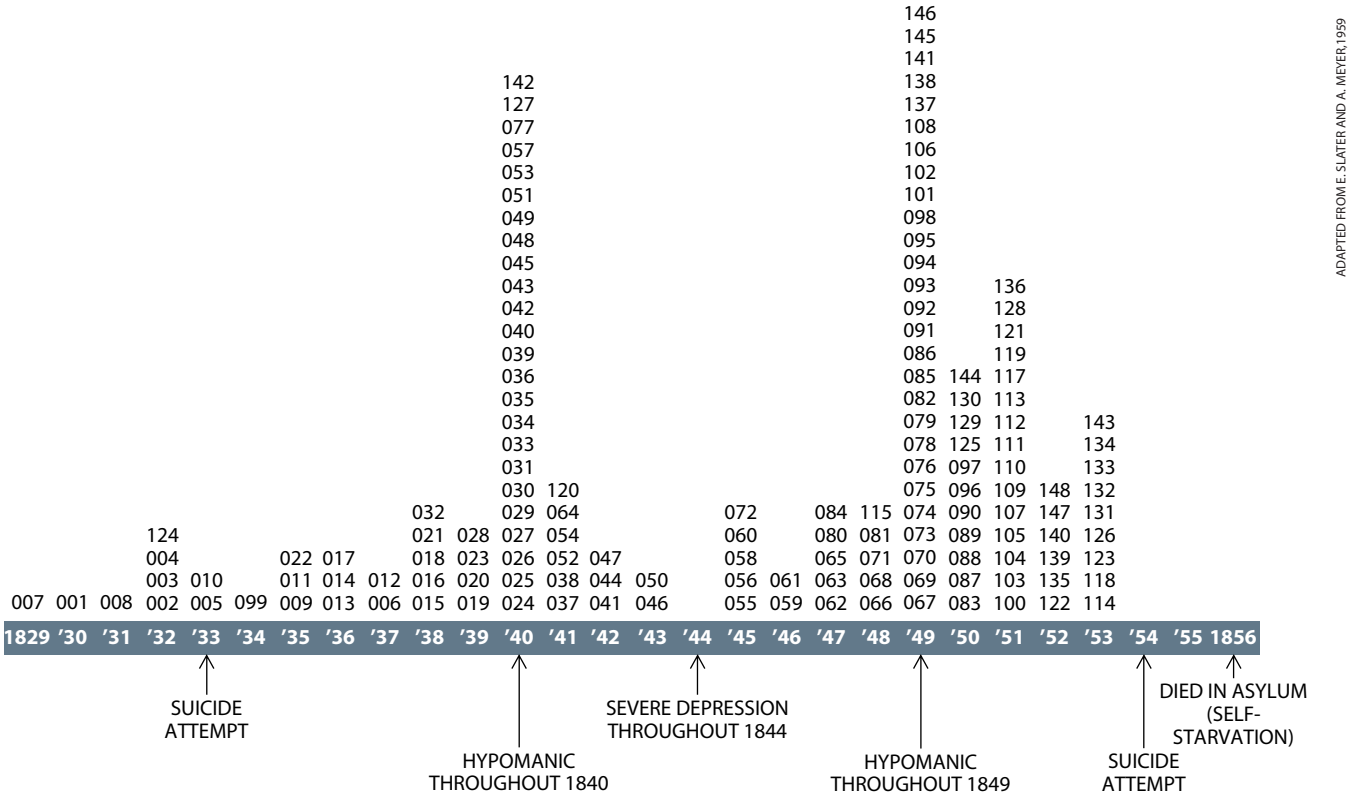
Many clinicians have reviewed the medical and psychiatric problems of the painter Vincent van Gogh posthumously, diagnosing him with a range of disorders, including epilepsy, schizophrenia, digitalis and absinthe poisoning, manic-depressive psychosis, acute intermittent porphyria and Ménière's disease.

Richard Jed Wyatt of the National Institute of Mental Health and I have argued in detail that van Gogh's symptoms, the natural course of his illness and his family psychiatric history strongly indicate manic-depressive illness. The extent of the artist's purported use of absinthe and convulsive behavior remains unclear; in any event, his psychiatric symptoms long predate any possible history of seizures. It is possible that he suffered from both an epileptic disorder and manic-depressive illness. —*K. R. J.*



LISA BURNETT

INCREASED RATES OF SUICIDE, depression and manic-depression among artists have been established by many separate studies. These investigations show that artists experience up to 18 times the rate of suicide seen in the general population, eight to 10 times the rate of depression and 10 to 20 times the rate of manic-depression and its milder form, cyclothymia.



ROBERT SCHUMANN'S MUSICAL WORKS, charted by year and opus number (*above*), show a striking relation between his mood states and his productivity. He composed the most when hypomanic and the least when depressed. Both of Schumann's parents were clinically depressed, and two other first-degree relatives committed suicide. Schumann himself attempted suicide twice and died in an insane asylum. One of his sons spent more than 30 years in a mental institution.

manic-depressives seek relief from the disease, and lithium and anticonvulsant drugs are very effective therapies for manias and depressions. Nevertheless, these drugs can dampen a person's general intellect and limit his or her emotional and perceptual range. For this reason, many manic-depressive patients stop taking these medications.

Left untreated, however, manic-depressive illness often worsens over time—and no one is creative when severely depressed, psychotic or dead. The attacks of both mania and depression tend to grow more frequent and more severe. Without regular treatment the disease eventually becomes less responsive to medication. In addition, bipolar and unipolar patients frequently abuse mood-altering substances, such as alcohol and illicit drugs, which can cause secondary medical and emotional burdens for manic-depressive and depressed patients.

The Goal of Treatment

The real task of imaginative, compassionate and effective treatment, therefore, is to give patients more meaningful choices than they are now afforded. Useful intervention must control the extremes of depression and psychosis without sacrificing crucial human emotions and experiences. Given time and increasingly sophisticated research, psychiatrists will likely gain a better understanding of the complex biological basis for mood disorders. Eventually, the development of new drugs should make it possible to treat manic-depressive individuals so that those aspects of temperament and cognition that are essential to the creative process remain intact.

The development of more specific and less problematic therapies should be swift once scientists find the gene, or genes, responsible for the disease. Prenatal tests and other diagnostic measures may then become available; these possibilities raise a host of complicated ethical issues. It would be irresponsible to romanticize such a painful, destructive and all too often deadly disease. Hence, 3 to 5 percent of the Human Genome Project's total budget (which is conservatively estimated at $3 billion) has been set aside for studies of the social, ethical and legal implications of genetic research. It is hoped that these investigations will examine the troubling issues surrounding manic-depression and major depression at length. To help those who have manic-depressive illness, or who are at risk for it, must be a major public health priority. SA

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originally published in January 1997

How the Blind Draw

Blind and sighted people use many of the same devices in sketching their surroundings, suggesting that vision and touch are closely linked

by John M. Kennedy

I first met Betty, a blind teenager in Toronto, as I was interviewing participants for an upcoming study of mine on touch perception in 1973. Betty had lost her sight at age two, when she was too young to have learned how to draw. So I was astonished when she told me that she liked to draw profiles of her family members. Before I began working with the blind, I had always thought of pictures as copies of the visible world. After all, we do not draw sounds, tastes or smells; we draw what we see. Thus, I had assumed that blind people would have little interest or talent in creating images. But as Betty's comments revealed that day, I was very wrong. Relying on her imagination and sense of touch, Betty enjoyed tracing out the distinctive shape of an individual's face on paper.

I was so intrigued by Betty's ability that I wanted to find out if other blind people could readily make useful illustrations—and if these drawings would be anything like the pictures sighted individuals use. In addition, I hoped to discover whether the blind could interpret the symbols commonly used by sighted people. To bring the blind into the flat, graphical world of the sighted, I turned to a number of tools, including models, wire displays and, most often, raised-line drawing kits, made available by the Swedish Organization for the Blind. These kits are basically stiff boards covered with a layer of rubber and a thin plastic sheet. The pressure from any ballpoint pen produces a raised line on the plastic sheet.

Thanks to this equipment, my colleagues and I have made some remarkable findings over the past 20 years, and this information has revised our understanding of sensory perception. Most significantly, we have learned that blind and sighted people share a form of pictorial shorthand. That is, they adopt many of the same devices in sketching their surroundings: for example, both groups use lines to represent the edges of surfaces. Both employ foreshortened shapes and converging lines to convey depth. Both typically portray scenes from a single vantage point. Both render extended or irregular lines to connote motion. And both use shapes that are symbolic, though not always visually correct, such as a heart or a star, to relay abstract messages. In sum, our work shows that even very basic pictures reflect far more than meets the eye.

Outlines

After meeting Betty, I wondered whether all blind people could appreciate facial profiles shown in outline. Over the years, I asked blind volunteers in North America and Europe to draw profiles of several kinds of objects. Most recently, I undertook a series of studies with Yvonne Eriksson of Linköping University and the Swedish Library of Talking Books and Braille. In 1993 we tested nine adults from Stockholm—three men and six women. Four were congenitally blind, three had lost their sight after the age of three, and two had minimal vision. Each subject examined four raised profiles, which Hans-Joergen Andersen, an undergraduate psychology student at Aarhus University in Denmark, made by gluing thin, plastic-coat-

ed wires to a flat metal board [*see upper illustration on next page*].

Eriksson and I asked the volunteers to describe the most prominent feature on each display using one of four labels: smile, curly hair, beard or large nose. Five of them—including one man who had been totally blind since birth—correctly identified all four pictures. Only one participant recognized none. On average, the group labeled 2.8 of the four outlines accurately. In comparison, when 18 sighted undergraduates in Toronto were blindfolded and given the same raised-line profiles, they scored only slightly better, matching up a mean of 3.1 out of four displays.

Many investigators in the U.S., Japan, Norway, Sweden, Spain and the U.K. have reported similar results, leaving little doubt that blind people can recognize the outline shape of familiar objects. At first, it may seem odd that even those who have never had any vision whatsoever possess some intuitive sense of how faces and other objects appear. But with further thought, the finding makes perfect sense. The lines in most simple drawings show one of two things: where two surfaces overlap, called an occluding edge, or where two surfaces meet in a corner. Neither feature need be seen to be perceived. Both can be discerned by touching.

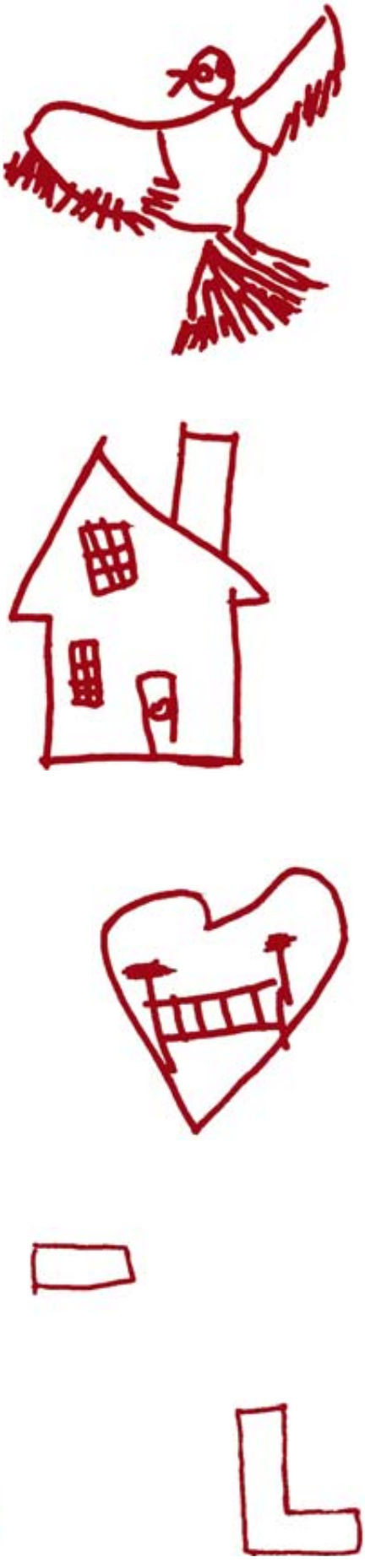
Not all blind people read raised-line drawings equally well, and these individual discrepancies can reflect the age at which someone lost his or her sight. For example, people who have been blind from birth or infancy—termed the early blind—sometimes find raised-line drawings challenging. But in 1993 Yatuka Shimizu of Tsukuba College of Technology in Japan, with colleagues Shinya Saida and Hiroshi Shimura, found that 60 percent of the early-blind subjects they studied could recognize the outline of common objects, such as a fish or a bottle. Recognition rates were somewhat higher for sighted, blindfolded subjects, who are more familiar with pictures in general.

Interestingly, subjects who lose vision later in life—called the later blind—frequently interpret raised outlines more readily than either sighted or early-blind individuals do, according to Morton Heller of Winston-Salem University. One likely explanation is that the later blind have a double advantage in these tasks: they are typically more familiar with pictures than are the early blind, and they have much better tactile skills than do the sighted.

Perspective

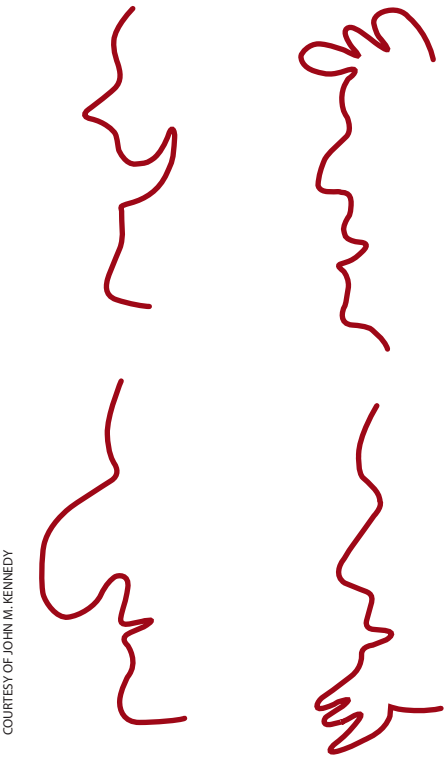
Just as Betty prompted me to study whether the blind appreciate profiles in outline, another amateur artist, Kathy from Ottawa, led me to investigate a different question. Kathy first participated in my studies when she was 30 years old. Because of retinal cancer detected during her first year of life, Kathy had been totally blind since age three and had never had detailed vision. Even so, she was quite good at making raised-line drawings. On one occasion Kathy sketched several different arrangements of a cube and an L-shaped block that I used to test how relative distances appear in line art. When the blocks sat side by side, she made them the same size—as they were in actuality. But when the cube was farther from her than the other block, she made it smaller in her drawing.

This second drawing revealed a fundamental principle of perspective—namely, that as an object becomes more distant, it subtends a smaller angle. (Think about viewing a picket fence at an angle



OUTLINE DRAWINGS, made by Kathy, totally blind since age three, demonstrate that blind artists use many of the same devices as sighted illustrators do. They use lines to represent surfaces, as Kathy's picture of the eagle on her charm bracelet shows (*top*). Blind people portray objects, such as a house, from a single vantage point (*at right*). Blind artists use shapes to convey abstract messages: Kathy drew a heart surrounding a crib to describe the love surrounding a child (*at right*). And they use foreshortening to suggest perspective: Kathy drew the L-shaped block and the cube to be the same size when they were side by side but made the cube smaller when it was placed farther away from her (*bottom*).

DRAWINGS COURTESY OF JOHN M. KENNEDY



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PROFILES, made from plastic-coated wires mounted on a thin metal board, were given to nine blind subjects in Stockholm. The subjects were asked to describe each display using one of four labels: smile, curly hair, beard or large nose. On average, the group described 2.8 of the four displays accurately, showing that blind people often recognize the outline of simple objects. Blindfolded, sighted control subjects given the same task did only slightly better.

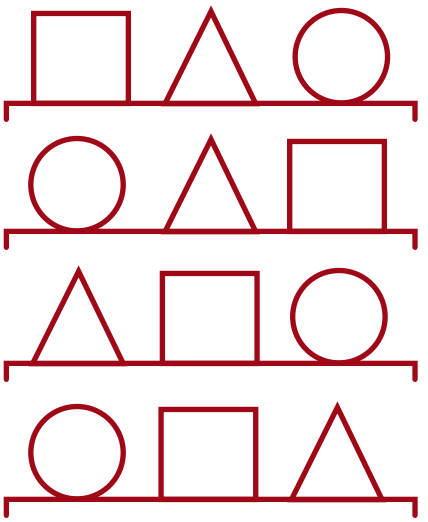
and how its posts appear shorter closer to the horizon.) Kathy's use of this basic rule suggested that some aspects of perspective might be readily understood by the blind. Again the proposition seemed reasonable, given some consideration. Just as we see objects from a particular vantage point, so, too, do we reach out for them from a certain spot. For proof of the theory, I designed a study with Paul Gabias of Okanagan University College in British Columbia, who was then at New York University.

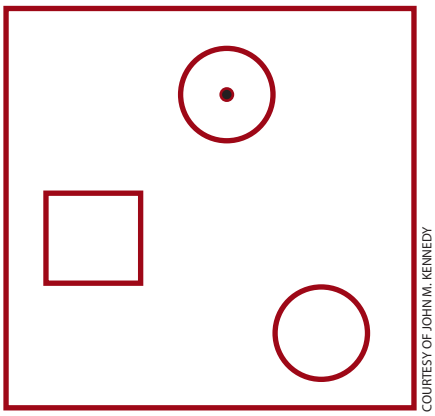
We prepared five raised-line drawings: one of a table and four of a cube [*see upper illustration on following page*]. We showed the drawings to 24 congenitally blind volunteers and asked them a series of questions. The table drawing had a central square and four legs, one protruding from each corner. The subjects were told that a blind person had drawn the table and had explained, "I've drawn it this way to show that it is symmetrical on all four sides." They were then told that another blind person had drawn an identical table but had offered a different explanation: "I've shown it from underneath in order to show the shape of the top and all four legs. If you show the table from above or from the side, you can't really show the top and all four legs, too."

Next we asked our volunteers to pick out the cube drawing that had most likely been made by the person who drew the table from below. To answer consistently, they needed to understand what strategy had been used in drawing the table and each cube. One cube resembled a foldout of a box, showing the front face of the cube in the middle, surrounded by its top, bottom, left and right faces. Another drawing showed two squares, representing the front and top of the cube. A third picture depicted the front of the cube as a square and the top as a rectangle—foreshortened because it was receding away from the observer. A fourth illustrated two trapeziums joined along the longest line; the extra length of this line revealed that it was the edge nearest to the observer.

Which cube do you think was drawn by the person who intended to show the table from below? Most of the blind volunteers chose the drawing that showed two trapeziums. That is, they selected the illustration that made the most sophisticated use of perspective. Accordingly, they picked as the least likely match the flat "foldout" drawing—the one that used no perspective whatsoever. The foldout drawing was also the one they judged most likely to have been made by the person who, in drawing the table, had hoped to highlight its symmetry.

Heller and I joined forces to prepare another task for demonstrating that the blind understood the use of perspective. (You might like to try it, too; it appears at the bottom of the opposite page.) We arranged three solids—a sphere, a cone and a cube—on a rectangular tabletop. Our blind subjects sat on one side. We asked them to draw the objects from where they were sitting and then to imagine four different views: from the other three sides of the table and from directly above as well. (Swiss child psy-





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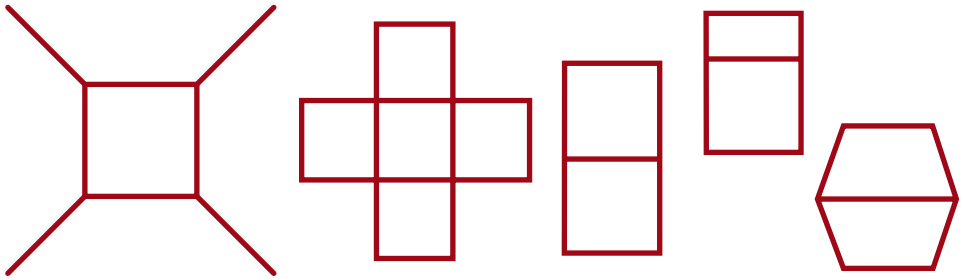
SOLIDS—a sphere, a cone and a cube—arranged on a table are commonly used to test spatial ability. The arrangement is shown from overhead at the far right. Which drawing at the near right shows the solids from the edge of the table facing the bottom of the page? Which drawing shows them from the opposite edge? From the edge facing left? Facing right? Blind and sighted individuals do equally well on this task, proving that the blind can determine how objects appear from particular vantage points.



COURTESY OF JOHN M. KENNEDY

PERSPECTIVE is readily understood by the blind. To prove this point, the author and Paul Gabias of Okanagan University College asked 24 congenitally blind volunteers to examine a drawing of a table (*far left*) and four drawings of a cube. They were told that one blind person drew the table in a star shape to show how it appeared from underneath and that another blind person drew an identical table, intending to show its symmetry instead. The subjects were then asked which cube was most likely drawn by the person who drew the table from underneath. Most chose the cube composed of two trapeziums (*far right*), the one that made the most sophisticated use of perspective.

chologist Jean Piaget called this exercise the perspective-taking, or "three mountains," task.) Many adults and children find this problem quite difficult. On average, however, our blind subjects performed as well as sighted control subjects, drawing 3.4 of the five images correctly.

Next, we asked our subjects to name the vantage point used in five separate drawings of the three objects. We presented the drawings to them twice, in random order, so that the highest possible score was 10 correct. Of that total, the blind subjects named an average of 6.7 correctly. Sighted subjects scored only a little higher, giving 7.5 correct answers on average. The nine later-blind subjects in the study fared slightly better than the congenitally blind and the sighted, scoring 4.2 on the drawing task and 8.3 on the recognition task. Again, the later blind probably scored so well because they have a familiarity with pictures and enhanced tactile skills.

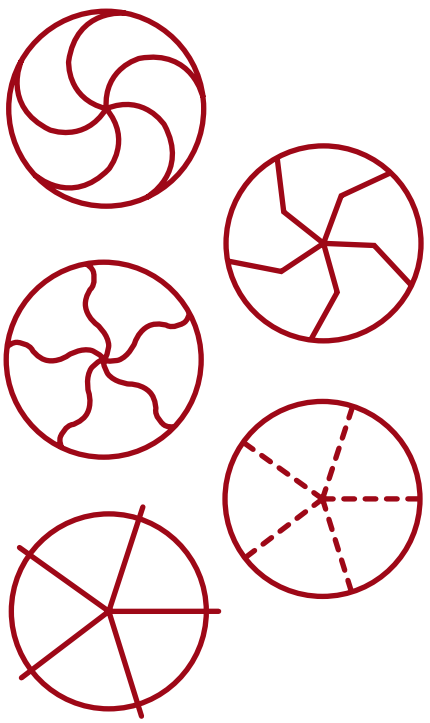
Metaphor

From the studies described above, it is clear that blind people can appreciate the use of outlines and perspective to describe the arrangement of objects and other surfaces in space. But pictures are more than literal representations. This fact was drawn to my attention dramatically when a blind woman in one of my investigations decided on her own initiative to draw a wheel as it was spinning. To show this motion, she traced a curve inside the circle. I was taken aback. Lines of motion, such as the one she used, are a very recent invention in the history of illustration. Indeed, as art scholar David Kunzle notes, Wilhelm Busch, a trendsetting 19th-century cartoonist, used virtually no motion lines in his popular figures until about 1877.

When I asked several other blind study subjects to draw a spinning wheel, one particularly clever rendition appeared repeatedly: several subjects showed the wheel's spokes as curved lines. When asked about these curves, they all described them as metaphorical ways of suggesting motion. Majority rule would argue that this device somehow indicated motion very well. But was it a better indicator than, say, broken or wavy lines—or any other kind of line, for that matter? The answer was not clear. So I decided to test whether various lines of motion were apt ways of showing movement or if they were merely idiosyncratic marks. Moreover, I wanted to discover whether there were differences in how the blind and the sighted interpreted lines of motion.

To search out these answers, Gabias and I created raised-line drawings of five different wheels, depicting spokes with lines that curved, bent, waved, dashed and extended beyond the perimeter of the wheel. We then asked 18 blind volunteers to assign one of the following motions to each wheel: wobbling, spinning fast, spinning steadily, jerking or braking. Which wheel do you think fits with each motion? Our control group consisted of 18 sighted undergraduates from the University of Toronto.

All but one of the blind subjects assigned distinctive motions to each wheel. In addition, the favored description for the sighted was the favored description for the blind in every instance. What is more, the consensus among the sighted was barely higher than that among the blind. Because motion devices are unfamiliar to the blind, the task we gave them involved some problem solving. Evidently, however, the blind not only



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MOTION can be suggested by irregular lines. When blind and sighted volunteers were shown five diagrams of moving wheels (*right*), they generally interpreted them in the same way. Most guessed that the curved spokes indicated that the wheel was spinning steadily; the wavy spokes, they thought, suggested that the wheel was wobbling; and the bent spokes were taken as a sign that the wheel was jerking. Subjects assumed that spokes extending beyond the wheel's perimeter signified that the wheel had its brakes on and that dashed spokes indicated that the wheel was spinning quickly.

WORDS ASSOCIATED WITH CIRCLE-SQUARE	AGREEMENT AMONG SUBJECTS (PERCENT)
SOFT-HARD	100
MOTHER-FATHER	94
HAPPY-SAD	94
GOOD-EVIL	89
LOVE-HATE	89
ALIVE-DEAD	87
BRIGHT-DARK	87
LIGHT-HEAVY	85
WARM-COLD	81
SUMMER-WINTER	81
WEAK-STRONG	79
FAST-SLOW	79
CAT-DOG	74
SPRING-FALL	74
QUIET-LOUD	62
WALKING-STANDING	62
ODD-EVEN	57
FAR-NEAR	53
PLANT-ANIMAL	53
DEEP-SHALLOW	51

WORD PAIRS were used to test the symbolism in abstract shapes—and whether blind and sighted people perceived such meanings in the same way. Subjects were told that in each pair of words, one fit best with circle and the other with square. For example, which shape better describes soft? According to the number given after the soft-hard word pair, everyone thought a circle did. These percentages show the level of consensus among sighted subjects. Blind volunteers made similar choices.

figured out meanings for each line of motion, but as a group they generally came up with the same meaning—at least as frequently as did sighted subjects.

We have found that the blind understand other kinds of visual metaphors as well. Kathy once drew a child's crib inside a heart—choosing that symbol, she said, to show that love surrounded the child. With Chang Hong Liu, a doctoral student from China, I have begun exploring how well blind people understand the symbolism behind shapes such as hearts, which do not directly represent their meaning. We gave a list of 20 pairs of words to sighted subjects and asked them to pick from each pair the term that best related to a circle and the term that best related to a square. (If you wish to try this yourself, the list of words can be found at the left.) For example, we asked: What goes with soft? A circle or a square? Which shape goes with hard?

All our subjects deemed the circle soft and the square hard. A full 94 percent ascribed happy to the circle, instead of sad. But other pairs revealed less agreement: 79 percent matched fast and slow to circle and square, respectively. And only 51 percent linked deep to circle and shallow to square. When we tested four totally blind volunteers using the same list, we found that their choices closely resembled those made by the sighted subjects. One man, who had been blind since birth, scored extremely well. He made only one match differing from the consensus, assigning "far" to square and "near" to circle. In fact, only a small majority of sighted subjects—53 percent—had paired far and near to the opposite partners. Thus, we concluded that the blind interpret abstract shapes as sighted people do.

Perception

We typically think of sight as the perceptual system by which shapes and surfaces speak to the mind. But as the empirical evidence discussed above demonstrates, touch can relay much of the same information. In some ways, this finding is not so surprising. When we see something, we know more or less how it will feel to the touch, and vice versa. Even so, touch and sight are two very different senses: one receives input in the form of pressure, and one responds to changes in light. How is it that they can then interpret something as simple as a line in exactly the same way? To answer this question, we must consider what kind of information it is that outlines impart to our senses.

The most obvious theory is that each border in a basic drawing represents one physical boundary around some surface or shape. But it is not that simple, because all lines, no matter how thin, have two sides or contours—an inside and an outside border, if you will. As a result, thick lines are perceived quite differently from thin ones. Consider a thick line tracing a profile. If it is thick enough, it appears to show two profiles, one per edge, gazing in the same direction [*see illustration below*]. When the line is thin and its two borders are close together, though, an observer perceives only one face. As it turns out, touch produces a similar effect. I prepared a series of profile drawings in which both edges of the defining line were raised. When the edges were only 0.1 centimeter apart, my blind volunteer, Sanne, a student at Aarhus University, said they showed one face. When they were 0.8 centimeter apart, she reported that they showed two faces.

Another theory of outline drawings suggests that lines substitute for any perceptible boundary, including those that are not tangible, such as shadows. But this theory, too, fails in a very telling fashion. Look at the illustration at the

THICKNESS of these outlines determines whether their two contours are viewed as one profile or two. The same ambiguity occurs with touch. Blind subjects interpret raised edges placed near each other as a single surface boundary and those placed farther apart as two.

COURTESY OF JOHN M. KENNEDY

SHADOWS, and other intangible boundaries, are not recognizable in outline—explaining in part why the blind can understand most line drawings made by sighted people. In the picture of the author on the left, a single contour separates light and dark areas of his face. In the picture on the right, a line, having two contours, makes the same division. Note that although the shapes are identical in both images, the perceptual results are quite different. Only the image on the left clearly resembles a face.

COURTESY OF JOHN M. KENNEDY

right, which shows two pictures of the author. In one image, shadow patterns, defined by a single contour separating light and dark areas, cross my face. In the second image, a dark line having two contours traces the same shadow patterns. Despite the fact that the shapes in the second picture are identical to those in the first, the perceptual results are vividly different. The first is easily recognized as a face; the second is not.

Again, this example shows that our visual system, like our tactile system, does not read two contours of a line in the same way as it interprets a single contour. The implication is that the brain region responsible for interpreting contours in sensory input from busy environments is a general surface-perception system. As such, it does not discriminate on the basis of purely visual matters, such as brightness and color. Rather it takes the two contours of a dark line and treats them as indicators for the location of a single edge of some surface. Whereas sighted individuals treat brightness borders as indicators of surface edges, the blind treat pressure borders in the same way.

Because the principles at work here are not just visual, the brain region that performs them could be called multimodal or, as it is more commonly termed, amodal. In one account, which I have discussed in my book on drawings by the blind, such an amodal system receives input from both vision and touch. The system considers the input as information about such features as occlusion, foreground and background, flat and curved surfaces, and vantage points. In the case of the sighted, visual and tactile signals are coordinated by this amodal system.

As we have found, the ability to interpret surface edges functions even when it does not receive any visual signals. It is for this very reason that the blind so readily appreciate line drawings and other graphic symbols. Knowing this fact should encourage scholars and educators to prepare materials for the blind that make vital use of pictures. Several groups around the world are doing just that. For instance, Art Education for the Blind, an organization associated with the Whitney Museum of American Art and the Museum of Modern Art in New York City, has prepared raised-line versions of Henri Matisse paintings and of cave art. It may not be long before raised pictures for the blind are as well known as Braille texts. SA

The Author

JOHN M. KENNEDY was born in Belfast in 1942 and was raised in one of the few Unitarian families in Northern Ireland. He attended the Royal Belfast Academical Institution and Queen's University of Belfast, where his interests included fencing and theater. He completed his Ph.D. in perception at Cornell University and began his research with the blind shortly thereafter as an assistant professor at Harvard University. He currently lectures at the University of Toronto, Scarborough College, where he won his college's teaching prize in 1994. Notes from his courses on perception are available through the university's World Wide Web site at http://citd.scar.utoronto.ca/Psychology/PSYC54/PSYC54.html

Further Reading

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