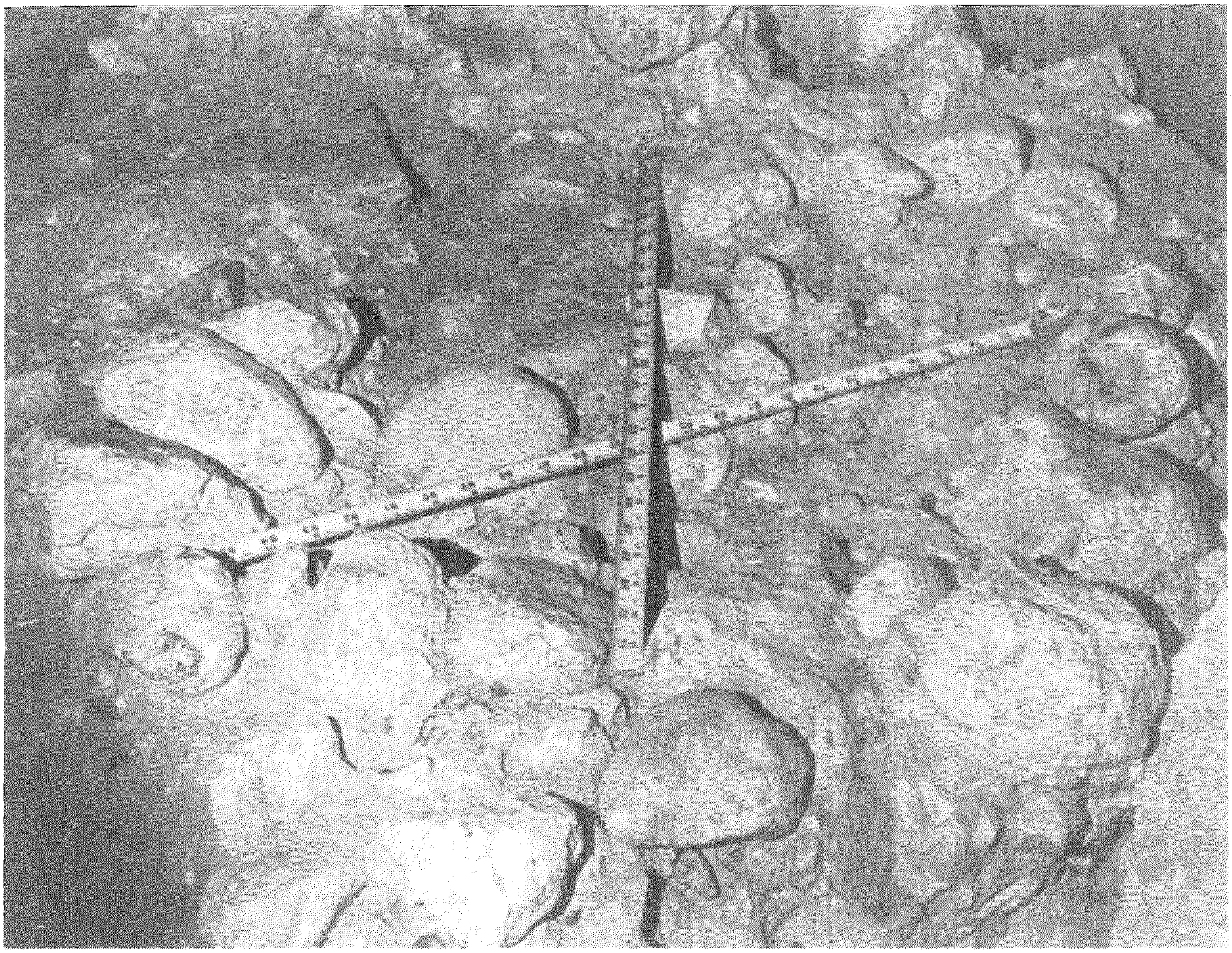
Research in Progress

Under the direction of Fredrick H. Shair, professor of chemical engineering, and with the financial support of many corporations and individuals, the Summer Undergraduate Research Fellowship (SURF) program is providing stipends for 126 students this summer. This month's Research in Progress *profiles four of these SURF projects.*



California's First Barbecue?

Somewhere near Barstow some 200,000 years ago a group of hominids may have dug a pit, surrounded it with stones, and set a campfire. Senior Janet Boley, working with Joseph Kirschvink, assistant professor of geobiology, is trying to determine whether an ancient ring of stones, looking for all the world like a carefully prepared hearth, actually housed a roaring fire. She's doing this by searching for the magnetic traces that would have been impressed on the stones by the fire's heat. Since most archaeologists believe that humans first came to North America between 12,000 and 25,000 years ago, Boley's results, if positive, would be revolutionary, pushing this date back by a full order of magnitude.

Several of these stone circles were discovered 50 feet under the surface of

Janet Boley points to a core hole she drilled in one of the putative ancient hearth-stones. She'll slice the core itself like a salami and will measure the magnetic moments of the resulting discs.

an alluvial fan — a cone-shaped deposit of sediment that forms at the mouth of a stream. Percolating ground water left a crust of caliche (calcium carbonate) on each buried stone, and this caliche has been dated by radiometric uranium/thorium methods to be at least 200,000 years old. Archaeologists have found thousands of possible human artifacts near the rings, most of which are apparently the remnants of stone tools. The majority of archaeologists would argue, however, that both the putative tools and the stone circles could have been formed by natural processes.

Boley's investigations of the magnetism of the stones may go a long way towards resolving this dispute. You can think of the stones as containing millions of magnetic crystals, each acting as a tiny compass, pointing in the direction that the earth's magnetic field pointed when the stone originally cooled from the molten state. When the postulated early human (who may actually have been a *Homo erectus*, the predecessor of *Homo sapiens*) gathered the stones and arranged them around the circle, the magnetic "moments" of each of the stones would have ended up pointing in a different random direction.

But the magnetic moments can be reset if their temperature is raised beyond the mineral's "Curie point." A roaring fire would have done just that, but only to the parts of the stones that got hottest, the parts facing the inside of the circle. And the magnetic moments of all the inside faces of the stones would have been reset to point in the same direction: the direction of the earth's magnetic field when the fire burned.

To test whether this actually happened, Boley drills cylindrical cores from each of the stones, carefully preserving the original orientation so that the core will go as directly as possible from the stone's inside to its outside face. She then slices these cores like a salami, ending up with discs that are the diameter of a quarter and a quarter-inch thick. Using a magnetometer, she measures the magnetic moments of each of the discs. She expects to see the direction of the magnetic moments gradually changing as she goes from discs that had been near the inside of the ring to those that had been near its outside. And when she correlates the magnetic moments of all the discs from all the cores taken from all the stones, she will see if the magnetic moments of the inside discs point in the direction of the earth's magnetic field, while the magnetic moments of the outer discs point in different directions from stone to stone. And, since different minerals within the stones have different Curie points, careful study may actually tell her not only whether a fire burned within the circle, but even just how hot that fire was.

Workers at the original site, along with JPL's Alan Gillespie, recently performed an important control experiment. They dug a pit, arranged locally collected stones in a circle around it, filled the pit with indigenous sagebrush, and lit a seven-hour bonfire, taking careful temperature measurements along the way. The glowing coals measured 700° C, and the stones measured 291° C on the inside, 90° C on the outside, and 200° C on the bottom. Boley is performing the same measurements on the control stones as on the others.

At this writing, measurements on only one core of one old stone have been completed. The results from this core are negative; there was no change in magnetic moment from one end of the core to the other. But Boley believes that the core may not have gone from the hot end to the cold end, and she's drilling another core from this stone oriented in another way. She's continuing with her measurements of cores from the other stones as well — both the actual ones and the controls — and she hopes to answer one of the most important questions in North American archaeology by the end of the summer. □
— *RF*

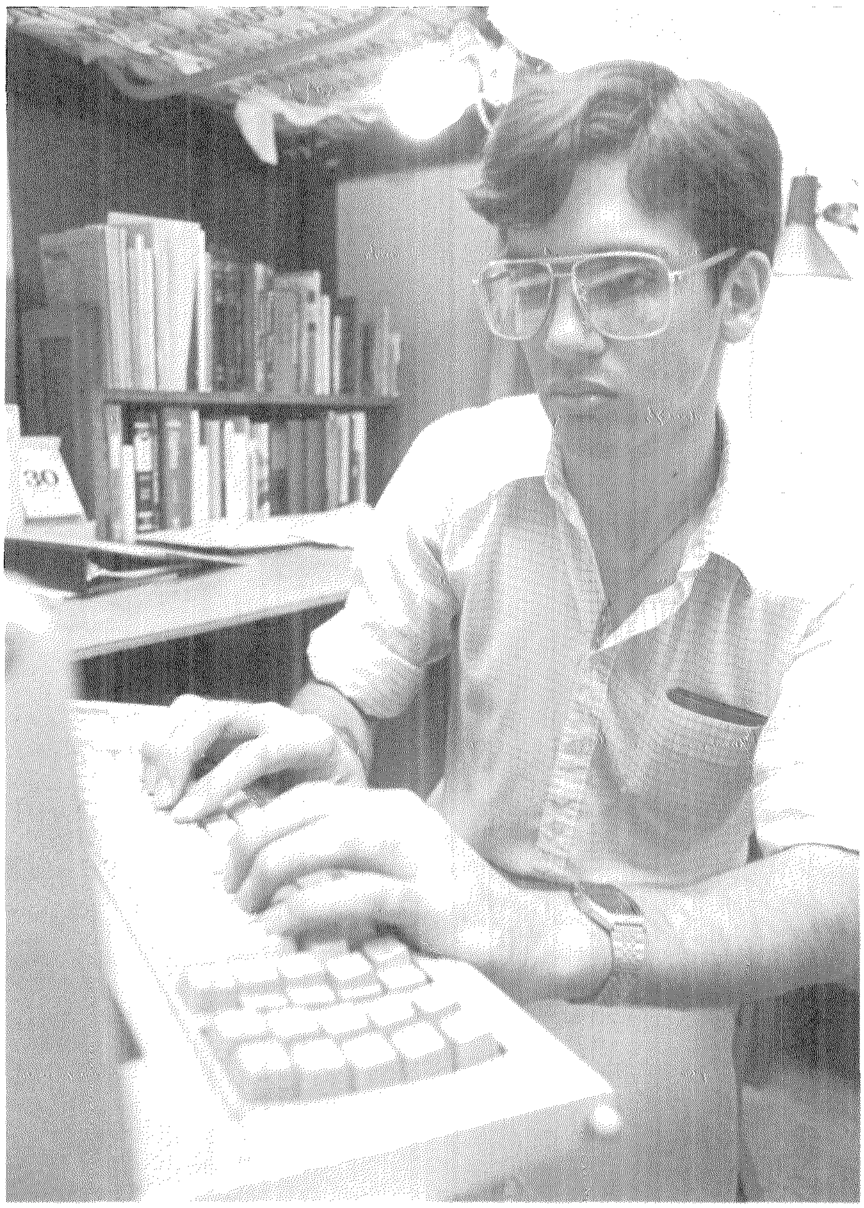
Power of a Tourney

MOST RESEARCH in mathematics relates to nothing in everyday experience and can't be described in ordinary language. But senior Art Duval is working on a project that is understandable to those unschooled in higher mathematics and may well have practical application too. He's working on the problem of ranking teams that have played an incomplete tournament.

There's no problem in ranking teams that have played a *complete* tournament, which is defined as one in which every team plays every other team exactly once. In that case, the highest ranking team is the one that wins the most games. But when every team doesn't play every other team, two problems arise in determining a ranking. One is the problem of cycles, in which team A beats team B, team B beats team C, and team C beats team A. The other problem is the problem of unbalanced schedules. Suppose there are 10 teams and half are tough opponents and half are easy opponents. Suppose further that team A plays four games against the easy teams, beating them all, while team B plays four games agains the tough teams, winning two and losing two. Because the schedules of A and B are unbalanced, it's difficult to compare their abilities.

There are some established methods for ranking teams in an incomplete tournament. These methods assume that each team has a certain amount of ability, which can be represented by a single real number. Given the results of an incomplete tournament, these methods attempt to determine how the unplayed games would most likely have come out. Duval, however, was bothered by the assumption that ability can be represented by a *single* real number and he decided to assume that a team's ability is indexed by two real numbers, representing, say, the separate abilities of the offense and the defense. Having made this assumption, Duval's first task was to determine how the two components could interact. "If one team's numbers are 3 and 7 and the other team's are 5 and 5, which one is better? Well, if you just add them up, for instance, then you don't really have two numbers at all. A lot of other methods come to the same thing. So I spent some time trying to find an interaction that didn't collapse into the one-dimensional case."

The method he came up with involves taking the difference between the first components of the two teams and adding that to a constant times the difference between the second components raised to some power. Duval then ran extensive simulations



where the computer randomly generated pairs of abilities for 25 teams and played the teams against each other. He was trying to determine the best values for the constant and the power term, values that would maximize the number of cycles in the tournament. This would give him something to work with in the next stage, in which he would try to modify the established methods to determine the dual abilities of teams in an incomplete tournament. Determining the proper constants, however, quickly turned into a problem in statistics, a problem that Duval did not feel ready to tackle just then, so he set it aside and began working on the problem of avoiding unbalanced schedules.

"If everyone plays the same number of games and if you distribute them properly, then no one should have too unbalanced a schedule. Obviously, you can't say you've got a method that definitely will get it because no matter how you do it, you can define the rankings in such a way that someone's playing all the best teams. But you can minimize the probability of that. Imagine spreading all the teams out on a table like a bunch of marbles. You wouldn't want to just play everyone within a small distance of yourself because it would be difficult to rank yourself against ones in the far corner." Duval has just finished a course in graph theory where he came upon something that struck him as applying to this problem — a type of graph called a "strongly regular graph." Says Duval, "A graph is just a bunch a vertices (which you can think of as teams) connected by a bunch of edges (which you can think of as games)." Duval is currently analyzing strongly regular graphs in this light.

Duval's project falls under the branch of mathematics called combinatorics. His faculty sponsor, Richard M. Wilson, professor of mathematics, defines combinatorics as, "that branch of mathematics that deals with arrangements of finite sets of objects." But he qualifies that statement in the peculiar manner mathematicians use when trying to express in ordinary English their ineffable interests: "That definition is not precise; in fact, it's meaningless, but at least it's true."

Will Duval's work have practical application? At first glance the National Football League with its 28 teams, each with a schedule of 16 games, seems like a perfect example of an incomplete tournament. "But they're not really after finding the best team," says Duval. "They're after selling lots of tickets." If the NFL could rank the teams after the regular season, there'd be no reason to go into playoffs. "As far as scheduling goes, there they also have different priorities. They're more interested in establishing rivalries than in making balanced schedules." But if the NFL isn't interested, other organizations may be. Food companies that conduct taste comparisons could use the methods Duval is developing to minimize the number of comparisons that they need to make to arrive at a valid ranking. Practical application, however, is not one of Duval's priorities. "Even if no application is found for 50 years, I think the math in it has turned out to be very interesting." □ — *RF*

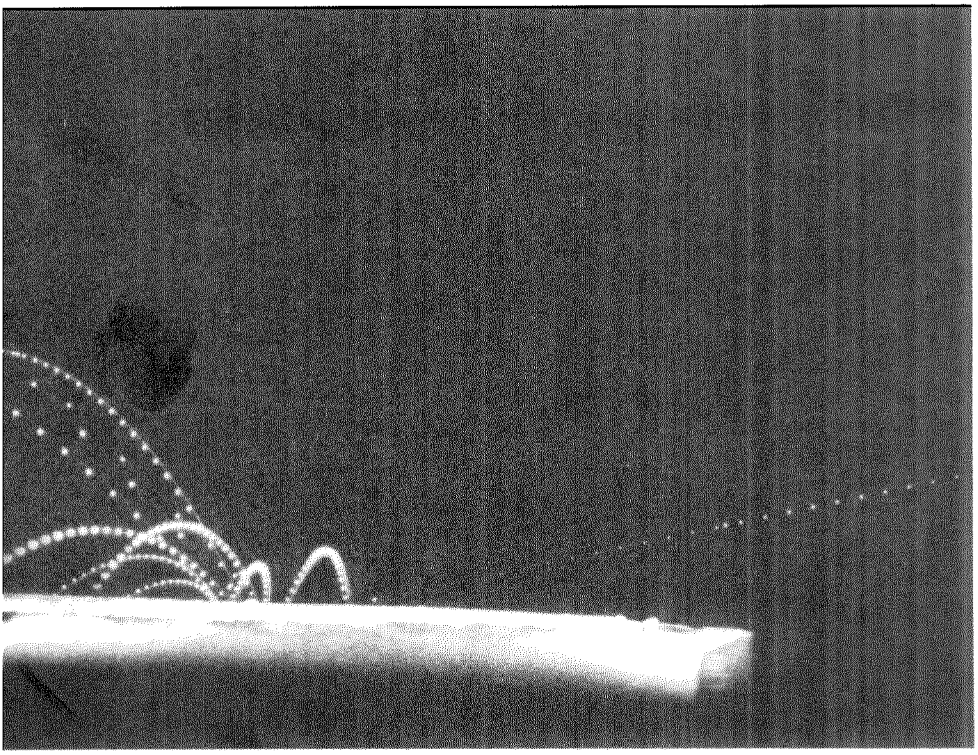
Dancing Sands

Beneath the sub-basement of the Kellogg Radiation Laboratory, in a room shrouded in black plastic sheets, sophomore Minh Tran shoots BBs from an air gun into a BB-filled box in an attempt to simulate the movements of sand in the wind. These experiments, which Tran conducts under the supervision of Peter Haff, senior research associate in physics, should lead to a better understanding of wind erosion and sand and dust storms and may help explain the origin of sand ripples — a beautiful and universal, yet still poorly understood, natural phenomenon.

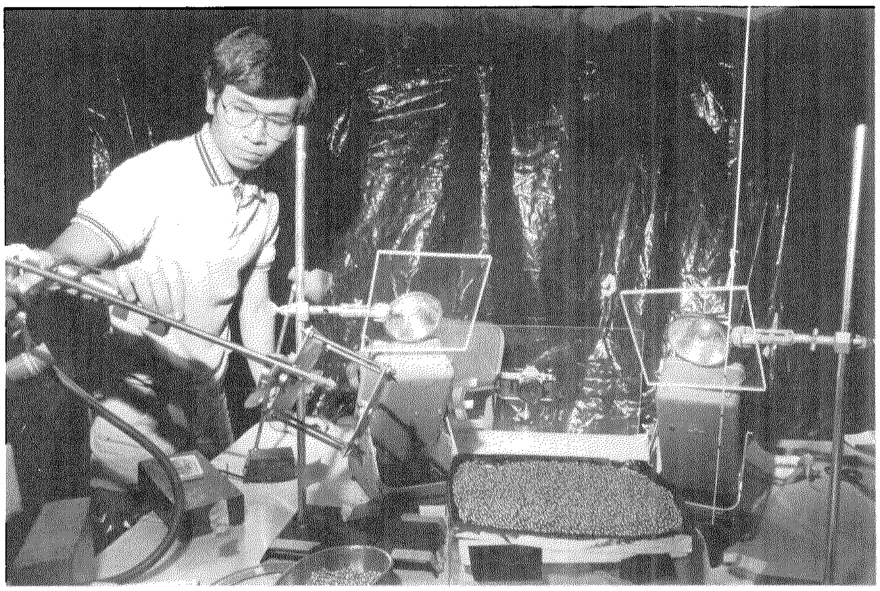
Wind-blown sand moves primarily by "saltating," a word that comes from the Latin *saltare*, which means "to jump." A grain of sand in the air is pushed forward, parallel to the ground, by the force of the wind, and it's pulled downward by the force of gravity. It hits the ground at an oblique angle and imparts its force to other sand grains, which jump off the ground, and are accelerated by the wind, eventually to strike still other sand grains a bit further on.

In fact, it is saltation that provides a rigorous definition for the word "sand." Sand particles, with typical diameters ranging from 0.15 to 0.3 mm, are just the right size to undergo saltation. Larger particles (pebbles) are too large to be bounced up and accelerated by the wind and are left behind as sand masses move. Smaller particles (dust) enter suspension in the air and can be blown many miles from their points of origin. Haff refers to the wind as "a giant winnowing machine" that separates sand from pebbles and dust.

With Tran's help, Haff is investigating three interconnected aspects of saltation. The first of these is a description of the aerodynamic forces acting on a sand grain. These forces, combined with gravity, determine the



To simulate sand blowing in the wind, Minh Tran fires BBs from an air gun into a BB-filled box, photographing the impact using two strobes. In the top photo a "sand grain" (coming from the right) blasts a number of others into the air.



grain's trajectory. The second aspect involves the feedback of the grains on the wind. As wind speed increases, it imparts more momentum to each sand grain, which in turn splashes up more grains at each impact. But additional airborne grains suck energy and momentum from the wind, damping it somewhat. In order to determine the extent of this damping, Haff needs to know the trajectory of the grains. But in order to describe the trajectory of the grains, Haff needs to know wind velocity. It's possible that this seemingly circular problem can be resolved by employing iterative calculations.

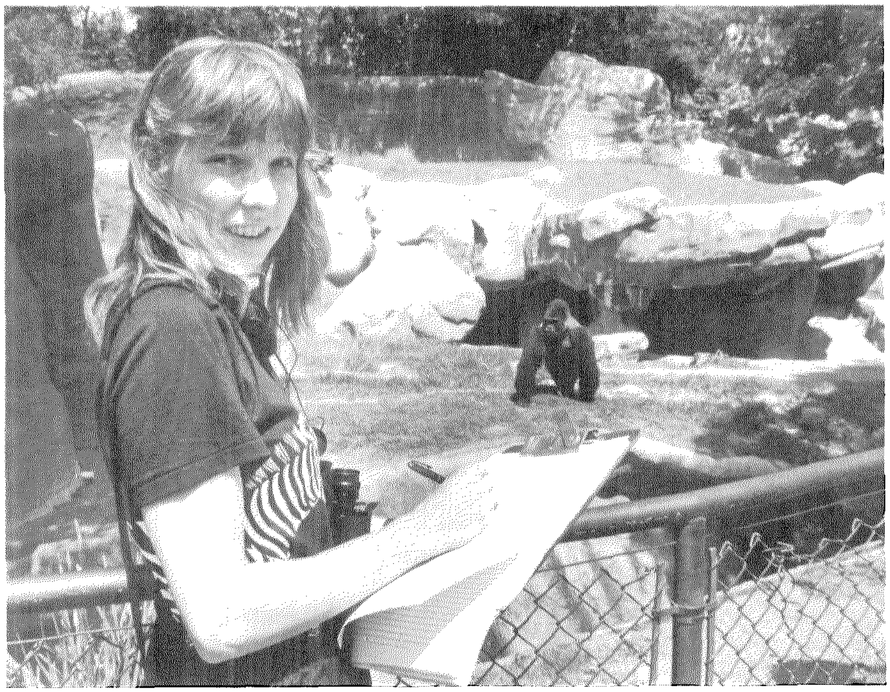
Tran is working on the third aspect of saltation, which involves describing the "splash function." He's trying to determine the distribution of splashed particles — how many are splashed up, how high they go, and what angles they go in — as a function of the energy and the angle of the incoming grain. Luckily, he's able to use metal BBs as stand-ins for sand grains in his experiments; otherwise he'd literally have to count individual grains of sand — something that not even an undergraduate can be persuaded to do.

Tran has also worked on experiments designed to determine the origin of sand ripples. Although the process of ripple formation is known in outline, many of the details remain to be worked out. A ripple starts to form when, by chance, there's a small bump on the surface. Since the wind drives saltating grains into the surface at an oblique angle, a larger number of impacts will occur on the windward side of the bump than on the leeward side. So there will be a bigger flux of sand on the windward side, sand will begin to accumulate, and the ripple will grow. It's still unclear, however, what determines how high a ripple will get or what causes the regular "wavelength" that's characteristic of a succession of ripples. Haff and Tran are trying to answer these questions using both experiment and computer simulation.

Although Haff insists "I'm doing ripples because they're fun," his work does have some practical applications. For one thing, ripples are occasionally preserved in lithified dunes. By studying "fossilized" ripples, geologists can determine the direction and velocity of ancient winds. And a better understanding of saltation will help us understand the growing problem of desertification. Many of the substances that make arable land arable are dust-sized, but it's difficult for this fine dust to enter suspension and be carried away unless it's first thrown into the air by the violent impact of a saltating sand grain.

Practical applications clearly take a back seat to aesthetic considerations when Haff discusses his interest in sand. He compares sand ripples to the rainbow. "If we didn't know where the rainbow came from, it would be something that a lot of people would be thinking about. Nobody needs a rainbow, but there it is — it's so neat that we ought to understand how it works. Sand rippling is one of those neat things that any child would notice and wonder about, but which we have no explanation for." □ — *RF*

Zoo Story



SENIOR KARYN BETZEN spends her summer days at the Los Angeles Zoo watching the animals. The recipient of one of this year's two off-campus SURFs, Betzen is serving as an animal behavior research intern, observing gorillas and alligators under the supervision of Dr. Cathleen Cox, the L.A. Zoo's research director. Betzen's gorilla studies are part of the zoo's crucial captive breeding program and her alligator work may help bring peace to the troubled alligator pond.

The pond is the home of six American alligators — a large male named Methusela and five smaller females. Recently, the zoo keepers began noticing an increased level of fighting among the alligators, fighting that has caused the deaths of four alligators. Betzen's assignment is to try to determine the cause of this discord. "I go out every half hour and I map where they are and what state they're in: are they swimming around, are they asleep, are they drowsy, or are they awake and just sitting there? They're most active early in the morning, between 8:30 and 10:00. If they're moving around and if they're interacting with each other, I stay out and watch the whole thing until they settle down again."

After about 10 days of doing this, Betzen discovered that it was one of the females, appropriately named Bad Temper, who was causing the problem. "It's as if she's saying, 'Okay, this half of the pond is mine. And you five can share the other half.' The keepers are pretty sure it's territoriality, but I'm not entirely sure. She could have some hormonal condition that's making her edgy. She seems to be awake most of the time while the others seem to be asleep half the time. This may indicate that there's something biologically wrong with her." The keepers plan to place some logs in the pond in order to block direct access to one section. This will decrease the amount of territory that Bad Temper can lay claim to. If this doesn't reduce the aggressive behavior, Betzen's hormonal hypothesis may well be correct.

Betzen's alligator project is pretty much her own, but she is also one of several people observing the zoo's gorillas. She's concentrating on an exhibit that houses four lowland gorillas: Tzambo, an adult silverback male; Lina, an adult female; Leo, an adolescent male; and Evie, an adolescent female. Tzambo was born in the wild, but Lina and Evie were born at the L.A. Zoo and Leo was born in captivity in Texas. Captive breeding of gorillas is a notoriously difficult task, but it may be the gorilla's only chance for survival. Says Betzen, "In the wild their numbers are dwindling fast. Their habitat is being industrialized very quickly. The future doesn't look good for them out there."

It's not known exactly why gorillas are so difficult to breed in captivity. "Sometimes the males tend to be shy," says Betzen. "If they're not reared in the wild, they've never seen other gorillas mate and so they don't know how. Also, a lot of times in captivity the males have low sperm counts, so even if they do mate the females don't get pregnant."

Betzen conducts four hours of concentrated gorilla observations each week. She comes armed with a cassette player with headphones that keeps her informed of the time and a clipboard to record her observations, and she spends 15 minutes recording the behavior of each of the gorillas. Among other things, she records how the gorillas relate to each other and she looks for signs indicating that a female has become sexually receptive. "The hardest part is weeding out when the gorillas are interacting with the audience, when they're doing something that they wouldn't ordinarily do. Leo hams it up for the audience. He'll throw leaves on his back, which is a thing gorillas do, but he'll be doing it because people are looking at him and laughing. Evie can pick out observers. I don't know if she knows me personally, but she can always tell observers by the headphones. She'll come up to the edge and blow me a kiss."

Betzen expects this summer's experience to be extremely valuable since she plans to apply to veterinary schools in the fall. She says that she's learning a great deal about the difficulties of doing behavioral research. One problem she continually encounters is the dearth of reliable information on the animals she studies. One reference work she found asserted that only male alligators bellow. But the *only* alligator that Betzen has witnessed bellowing was a female. In frustration she says, "It's hard to do research on alligators. A lot of what you read about them is not true." □ — *RF*