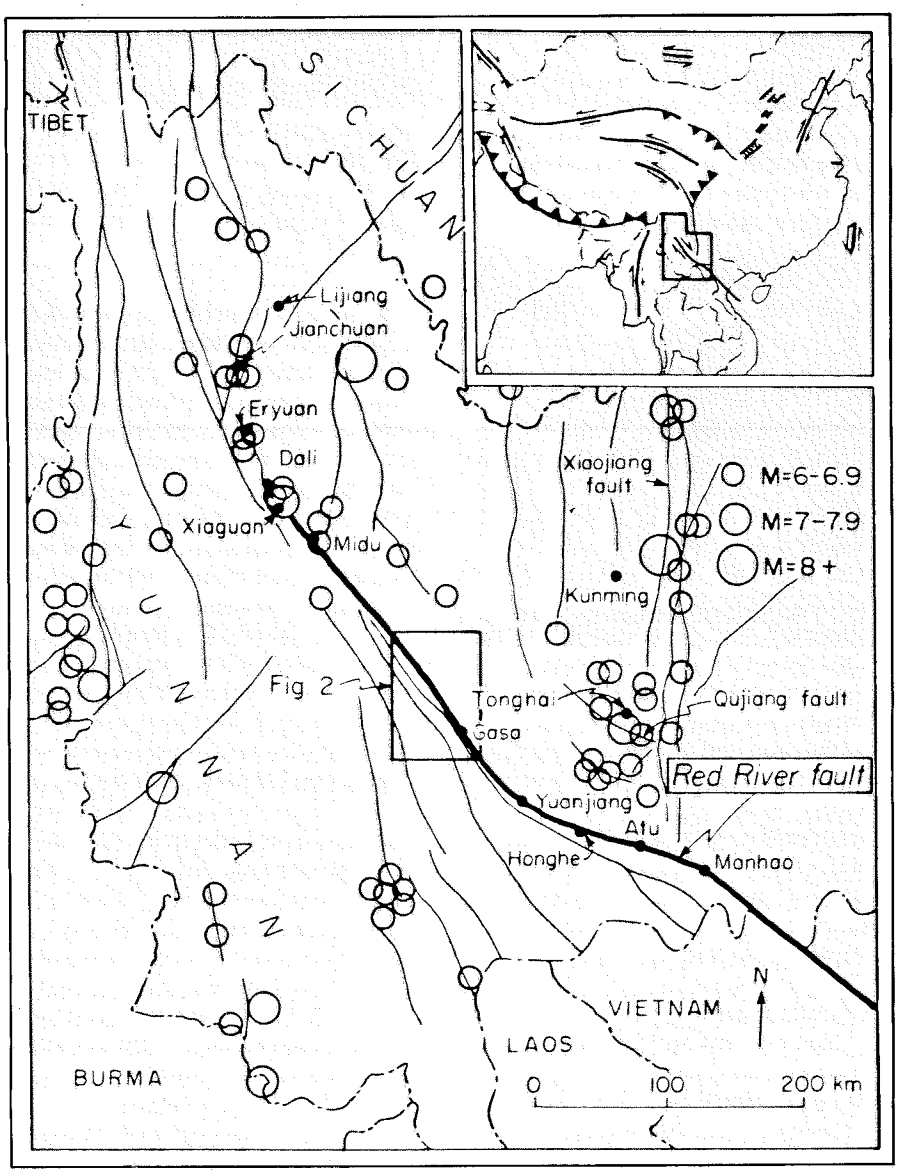
China's Fault

Studying earthquake faults in rural China, with all the attendant logistical problems, may not be the most comfortable — or effective — way to pursue research, but it has its rewards. For one thing, it's socially useful, says Kerry Sieh, associate professor of geology, who spent three months there last spring with his family and graduate student Ray Weldon. Of all countries, China is most prone to large destructive earthquakes, and determining the probability of one's occurrence on a particular fault could help save hundreds of thousands of lives.

For another, China's geology is scientifically exciting. Ever since the Indian subcontinent began to collide with Asia 45 million years ago, China has been trying to get out of the way, squeezing, wrinkling, and faulting its way out to the east and south. One of the great faults activated during this process, the Red River fault, which runs for several hundred kilometers through China's Yunnan Province, was the object of Sieh's 1983 journey.

Several years ago most Chinese geologists had thought this ancient fault to be safely inactive. But, based on interpretation of satellite imagery, Clarence Allen, professor of geology and geophysics, suspected that it was an active fault capable of a great earthquake. With a group of Chinese geologists, Allen and Sieh visited the area in 1981 and confirmed up to six kilometers of geologically youthful, right-lateral offset along the fault. They speculate that this offset may have accumulated during the last 1 or 2 million years. They also found evidence of younger, even more recent fault activity.

But how recent? To be of any practical value to the Chinese, the likelihood of a large earthquake there would have to be quantified. So Sieh returned to Yunnan, a province that borders on Vietnam, Laos, Thailand, and Burma, for three months last spring to study evidence of the behavior of the Red River fault over the past few thousand years. He looked for offsets in young landforms and sediments and excavated for specific signs of earthquakes in particular layers of sediment, layers that can be radiocarbon dated. A sequence of such earthquake dates gives a good picture of the frequency at which earthquakes occur on a given fault and, consequently, a general idea of when to expect the next one. His work on the San Andreas fault, for example, has indicated that southern California, where the last big quake hit in 1857 and the repeat time for such quakes has been about 150 years, has about a 50 percent chance of experiencing a quake of



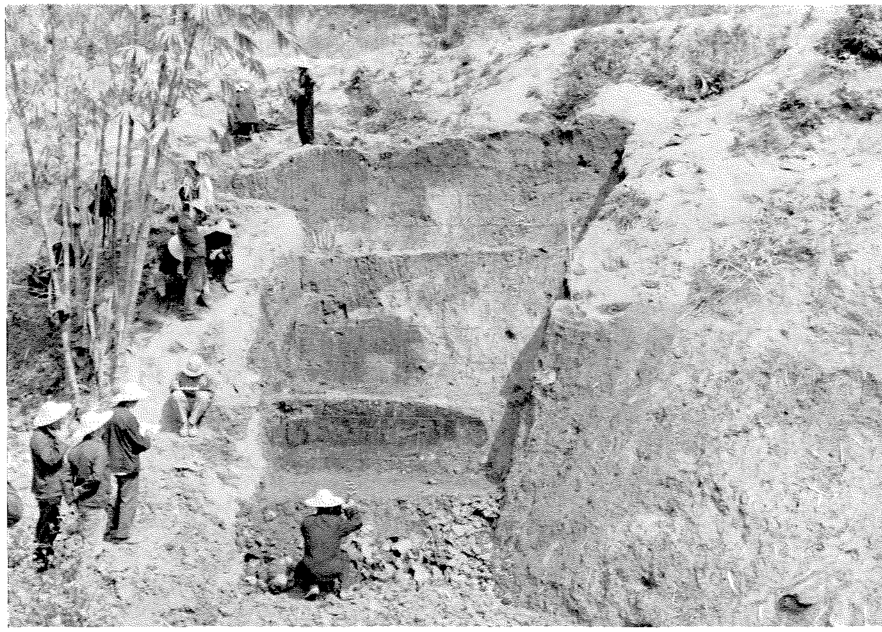
The Red River fault angles southeast from India's impact with Asia (inset). Circles indicate historical earthquakes of various magnitudes, none of them along the major section of the fault itself. Sieh's group excavated at Gasa (center) and Dali (to the northwest) in search of older earthquake clues.

magnitude 8 or larger in the next 50 years.

Local historical records, which are fairly complete for the past 500 years in Yunnan, mention no earthquake along the Red River fault. This says nothing more than that the average recurrence interval is probably more than 500 years, and if the last quake was, say, 600 years ago, another could be imminent. Sieh and his Chinese colleagues returned to one site (dubbed Butterfly Creek by Sieh for its abundance of butterflies when he and Allen visited it in 1981) and found it to be particularly interesting — especially since it was now the wrong time of year for butterflies and Sieh, who collects them, wasn't distracted. With the help of local Dai farmers using hoes, Sieh and his colleagues excavated the site, uncovering, as the cut became larger and larger, evidence of five large earthquakes in the sediment that had accumulated in the creek. Knowledge of those five events will help establish a reliable picture of the frequency of the Red River fault's movement.

Sieh took samples — for radiocarbon dating — from this and two other sites in southern and western Yunnan, but was shocked and frustrated on his arrival in China to learn that he would not be able to take them out of China for analysis. This apparent setback was resolved, however, when the radiocarbon samples mysteriously showed up on his doorstep in late October. Additional samples are expected to arrive with a team of Chinese geologists who will visit Caltech in the spring. These are paleomagnetic and soils samples, which the Chinese will participate in analyzing. Tests are not yet complete on any of the samples, but when the dates of the earthquakes and the average recurrence interval are determined, the Chinese will know whether they should prepare for an imminent event on the Red River fault or forget about it and aim their efforts at more dangerous faults. In addition, a better understanding of the activity of the Red River fault will help fill in the "big picture" of India's collision with Asia.

Sieh says that his family's experiences living in rural China were sufficiently rich and rewarding to outweigh the difficulties of working in an unfamiliar country and culture. He is hopeful about continued research in China because "the geology of China is alluringly active, and its awesome natural hazards challenge mitigation." □ — *JD*



At "Butterfly Creek" in Gasa, along the Red River fault, Chinese geologists and Caltech grad student Ray Weldon (sitting, left center) take notes on an early stage of the excavations. Evidence of five earthquakes was eventually found here.

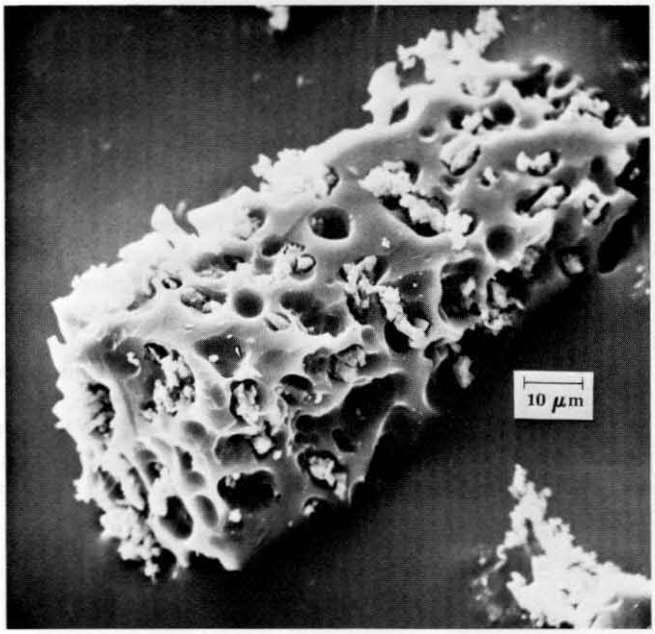
Fake Coal

About four years ago Richard Flagan was examining the structure of fine ash particles with an electron microscope at the Jet Propulsion Laboratory, when he noticed some pictures on the wall that looked strikingly familiar. The pictures were electron micrographs of silicon particles from a JPL project to produce silicon for photovoltaic cells, but to Flagan, associate professor of environmental engineering science at Caltech, they looked exactly like ash particles from coal combustion. He was intrigued enough to follow it up.

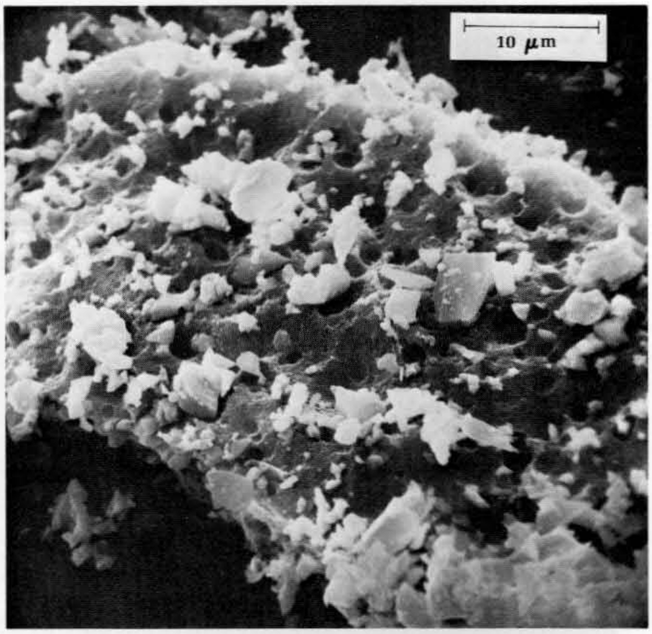
Combustion, not silicon production, is actually Flagan's area of expertise. His research has involved study of the formation of aerosols (suspended particles) produced from gases, in particular ash from burning coal. Ash is mineral matter that typically makes up about 10 percent of ordinary U.S. coal. Coal-fired utility plants burn coal as a powder, with particles reaching temperatures as high as 2000°C, high enough to vaporize a small fraction of the ash, even portions of those constituents not usually thought of as volatile.

Coal ash had previously been thought merely a nuisance by engineers, since control devices remove about 98-99 percent of it from the effluent. Control devices, however, remove the larger particles more efficiently than the smaller ones, letting escape some of the small ones, which don't settle out to collect visibly on windowsills but can invisibly find their way deep into human lungs. And research eight years ago showed that the smaller the particles of ash, the more heavily enriched they are with toxic heavy metals and other trace species.

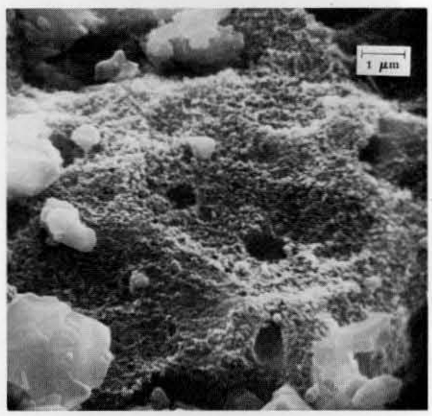
The dynamics of coal ash evolution has been far from completely understood. Aerosol particles can condense directly out of the vapor to form very small (a few nanometers), new particles, which then grow by coagulation. Unfortunately it's difficult to build a predictive model for the vaporization of ash because coal is such complex stuff that its thermodynamic properties are not known. Its chemical mixture can differ from batch to batch, even from particle to particle, and it changes so much during the combustion process that it has been impossible to examine any general mechanisms of vaporization. As a way of simulating coal combustion while avoiding the complicated chemistry of coal, Flagan and former graduate student Connie Senior developed a synthetic coal — a glassy carbon, whose porosity could be controlled and whose ash is simply quartz (silica). They will also use different ash materials in subsequent experiments.



The electron micrograph, above, of partially burned, non-porous, synthetic coal shows depressions forming under the ash (whiter particles), since the oxygen can attack the carbon through cracks, which occur primarily around the ash, causing increased vaporization.



Partially burned, porous carbon, on the other hand (above), is pitted all over. This is caused by a similar mechanism--oxidation of the carbon in the particle's interior due to oxygen diffusion into the many small pores, visible in the greater enlargement below.



In the synthetic coal Flagan and Senior have a tool that allows them to study the role of pore structure in coal combustion and gasification. Burning this simple, known substance as a powder under carefully controlled conditions has enabled them to observe how vaporization occurs on the surface of the powder particles and in the pores, which, as they open up during burning, allow more vaporization. A major factor in vaporization is reduction of the ash oxides to more volatile forms; this occurs to a greater extent inside the particles where the oxygen content is much lower than on their surface. In their experiments only about one-fourth of a gram of coal is burned per hour, heated to a reactor wall temperature of 1300°C; the burning particles themselves are much hotter. Measurements of the temperature of individual burning particles are now being made in order to provide a complete enough description to be able to test detailed models of the process.

Scanning electron micrographs of the synthetic coal have provided enormous insight into these mechanisms. And it was also the electron microscope that led from Flagan's coal ash work directly, and unexpectedly, to a high-technology spinoff. The pictures on the wall at JPL were of silicon particles produced in a free-space reactor, an attempt as part of the Flat Plate Solar Array Project to develop a new technology for producing high-quality silicon. Conventional silicon production methods use so much power that the silicon currently available is very expensive for use in solar cells.

In the free-space reactor, silicon particles nucleated out of silane gas (SiH_4) then were collected and melted to make the single silicon crystal necessary for a photovoltaic cell. But the particles were smaller than a micron, so small that collecting and melting them was extremely difficult. Efforts to increase particle size in the free-space reactor had been unsuccessful. Since Flagan was already working with silica (silicon dioxide) particles vaporized out of his synthetic coal, he and grad student M. K. Alam undertook to figure out how to grow larger particles of silicon for the JPL project (funded by the Department of Energy).

Flagan and Alam discovered that conditions in the free-space reactor generated too many particles in the system. For so many particles to then grow to sufficient size in vapor deposition, an unfeasibly large amount of pressure would be required. Their solution was to limit the number of particles formed in the initial burst of nucleation. By designing a small two-stage reactor that quenched the nucleation and separated it from the growth process, which must be carefully controlled to prevent any additional nucleation, they produced silicon particles 9 microns in diameter and hope in the larger reactor they are now building to push that size to 50 or even 100 microns. Another advantage of Flagan's procedure is that it is continuous; previous methods were batch processes.

Now that they have a chemical process that works, purity is the main concern, since silicon for photovoltaics must be much purer than that for electronics. But Flagan believes that his method has the potential for a very high degree of purity because the silicon never touches a solid surface. The process is also energy efficient, a necessary condition if solar cells are ever to become practical. And they are now quite close, he believes, to becoming practical. □ — *JD*