with the same surgery, the rats cease to self-administer cocaine. Koob interprets this to mean that the dopamine connection leading from the ventral tegmental area to the nucleus accumbens is critical for cocaine dependence but not for opiate dependence.

Wise disagrees. "Koob and I both envision a brain circuit that has several entry points," he says. "Koob thinks that the nucleus accumbens is the most sensitive site for drug action and we think the ventral tegmental area is the most sensitive. It is like a chain of nerve cells. Drugs can activate neurons at link 1 or link 2. We study link 1 where dopamine is the transmitter, and Koob studies link 2."

Koob and Wise also clash on whether the same brain pathway is responsible for both the pleasurable and painful aspects of drug use. For Koob, it is the same. His idea is a modernized version of the viewpoint held 30 or more years ago that physical dependence on drugs was the key to addiction. "The nucleus accumbens seems to be important for both psychological and physical dependence. I think that it somehow becomes sensitized in animals that are physically dependent."

Koob's reversion to the 1950s concept of drug dependence is an anathema to Wise, who sees a clear separation between the psychological mechanisms of pleasure and physical dependence on drugs. "We tend to look at the ventral tegmental area and its link to the nucleus accumbens as a pleasure mechanism, and the periaqueductal gray area (PAG) as a pain mechanism," says Wise. The PAG is composed of nerve cell bodies that surround the central canal connecting two of the major fluid-filled cavities in the brain called ventricles. According to Wise, opiate drugs act in the PAG to alleviate three kinds of pain—physical pain, the pain of loneliness and social withdrawal, and the drug-induced pain of opiate withdrawal.

Wise also challenges Koob's use of the term psychological to describe drug dependence. "The notion of physical dependence is clear," he says. "Extending it to include psychological dependence is messy because we have no way to measure that aspect objectively. I think there should be a big distinction between physical dependence—which is what people were talking about in the 1950s—and psychological dependence."

"Obviously, more work is needed to assess the behavioral changes associated with physical dependence and the underlying changes in the brain," says Koob. "I think physical dependence has manifestations all over the brain. The question is what responses go with what systems, and what drives drug-seeking behavior?" ■

DEBORAH M. BARNES

Geophysics: Ancient Air, Ozone, and Faults

Researchers who gathered in San Francisco in December at the annual fall meeting of the American Geophysical Union heard the usual variety of talks treating everything from Earth's core to the tenuous wisps of solar particles far beyond Pluto. Earthquakes, the local California variety in particular, figured prominently, as did the currently popular subjects of ancient air trapped in amber and the deepening Antarctic ozone hole.

No Ancient Air to Be Found in Amber?

The latest analyses of the air trapped for tens of millions of years in fossilized tree resin are in. They totally contradict earlier, independent analyses that indicated complete preservation of samples of an oxygen-enriched atmosphere of 80 million years ago.

In October Robert Berner of Yale University and Gary Landis of the U.S. Geological Survey (USGS) in Denver reported that cracking open 80-million-year-old amber released gases that, after an adjustment for the conversion of oxygen to carbon dioxide, resembled modern air but with about 30% rather than 21% oxygen (*Science*, 13 November, p. 890). The gases released from Baltic amber, which formed about 40 million years ago, contained about 21% oxygen.

But Yoshio Horibe and Harmon Craig of Scripps Institution of Oceanography reported at the AGU meeting that when they ground up their samples of Baltic amber in a ball mill, the gas released bore no resemblance to air, modern or ancient. Instead, it appeared to be a well-preserved sample of the gases that would have been dissolved in the sap of the tree that produced the amber. The ratio of nitrogen to argon was 39, as it is in oceans and lakes, not 84, as it is in air. The ratio of oxygen to argon was 0.4, not 22, as it is in air.

There is enough carbon dioxide to account for the missing oxygen, Craig noted, but he doubts that it is that simple. Oxygen exposed to amber in the laboratory at 107°C disappears within a few days, he and his colleague found. At room temperature, the half-life of oxygen was about a month, not millions of years. And they found that oxygen consumed by reactions with the amber did not reappear in carbon dioxide. They conclude that any carbon dioxide present in amber now was there when the resin formed or somehow reappeared.

The Scripps group would thus be surprised to find the gases trapped in amber enriched in oxygen, as reported by Berner and Landis. If oxygen were found in higher amounts than in air, they would conclude that it was enriched over the concentration in air because its greater solubility enriches it in any water solution.

The only significant differences between the two studies seem to be the analysis of different samples and the gas extraction by grinding or cracking. A sample exchange is under way.

A Hidden Earthquake Hazard in Los Angeles

The moderate Whittier Narrows earthquake that struck Los Angeles last October did not occur on the Whittier Fault, according to seismologists at a hastily organized session of the AGU meeting. Instead it ruptured a previously unknown, hidden fault more than 11 kilometers beneath the surface. That is bad news for residents of the Los Angeles basin, who already face the threat from 95 known faults that break the surface (*Science,* 16 October, p. 269).

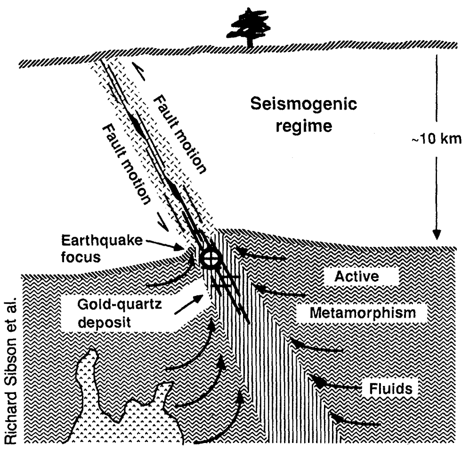
Egill Hauksson of the University of Southern California reported that a patch of fault slipped that is aligned in an east-west direction and dips at a gentle 30-degree angle to the north. It lies in the basement rock beneath an upward arching fold of sediment called an anticline. Jian Lin of Brown University and Ross Stein of the USGS in Menlo Park reported leveling measurements that showed that the fold had grown about 45 millimeters during the earthquake, which could be accounted for by about 1 meter's slip on the fault buried within the heart of the fold. The Coalinga earthquake of 1983, which also took seismologists by surprise, led to anticline growth in just the same way.

Hauksson pointed out that the Whittier Narrows earthquake and its associated fold are not unique. The fold is part of a trend extending from east of Whittier Narrows westward around the northern edge of the basin all the way to the Channel Islands. The moderate-size Point Mugu and Malibu earthquakes of the 1970s were associated with the same trend. North of it, similar thrusting of the upper side of a fault over the lower is obvious in surface breaks in the Transverse Ranges that enclose the basin. Although suggested long ago and since neglected, noted Hauksson, "this fault system has not been taken into account in evaluating the earthquake hazards in the Los Angeles Basin. The hazard may be somewhat underestimated."

How much underestimated is not clear. The relatively short historical record is not a good guide. An alternative is the geological record. Thom Davis, a Los Angeles geological consultant, has, on paper, unfolded the Los Angeles basin, restoring it to its condition 3 million years ago before it became crumpled like a rug on a slippery floor. He estimates that the basin has been compressed on average about 12 millimeters per year.

That rate of compression today would create far too many earthquakes if all the slippage led to earthquakes the size of Whittier Narrows. Seismologists and geologists will thus have to figure out just how the basin is behaving today in order to estimate the hazard more accurately. But even a modest increase in the hazard would imply that things could get pretty rough even before the big one arrives.

Making Faults Weak Enough to Slip



Richard Sibson et al.

How to ease fault squeeze. *A fault inclined this steeply should not slip when it is squeezed by crustal compression. But such faults penetrated by Canadian gold mines apparently did, thanks to the counteracting pressure of fluids along the fault.*

As evidence accumulates that the San Andreas fault may offer little resistance to the motion of the plates that meet there (*Science,* 24 April, p. 388), a group of geologists is suggesting an explanation for another kind of fault that should be tightly stuck but slips anyway. As a bonus, they may explain how some of the world's richest gold deposits formed.

At the meeting Richard Sibson of the University of California at Santa Barbara and Francois Robert and Howard Poulsen of the Geological Survey of Canada proposed that high fluid pressures developing 10 kilometers below the surface can tend to pry apart certain faults until they slip, fracturing the crust toward the surface and allowing the fluid to escape. To reach that conclusion they studied a number of long-dead faults penetrated by gold mine shafts, including the Sigma Mine at Val d'Or in Quebec. Gold from similar 2-billion-year-old faults accounts for half of Canadian production. The 100-million-year-old Mother Lode in California is of the same type.

A curious thing about the fault that plunges through the Sigma Mine at a 70-degree angle is that the blocks of rock on either side of it should not have slipped vertically past each other, but they obviously did. Inspection of the mineral-filled fault veins and subsidiary fractures shows that when the gold was being deposited during the last episode of activity on the fault, crustal stresses were squeezing the fault together so as to lock it. A steeply inclined fault such as this would be assumed to be active only when the crust is being pulled apart, not compressed. Increasing the compressive stress would only have locked it tighter and eventually broken fresh rock along a new, more gently inclined fault at an angle closer to 30 degrees.

Another curiosity is the obvious repetition of mineral deposition in the veins. Conditions returned time and again that favored the deposition of minerals originally dissolved in a fluid. Repeated, drastic reductions of pressure might suffice, but that was thought to require an unlikely slow cycling between crustal extension and compression.

Sibson and his colleagues propose to resolve both enigmas with a single mechanism—a fault that acts like a valve to shut in slowly pressurizing fluids and then rapidly release the pressure immediately after an earthquake. In their model, the pressure of fluids in the rock would rise above that from the weight of overlying rock as water, carbon dioxide, and other volatiles are cooked out of deeper rocks or escape from magma and become trapped about 10 kilometers below the surface. The presence of horizontal, mineral-filled fractures attests to the existence of such pressures.

To judge from the sometimes brittle fracturing, sometimes ductile flowing of the rock, the depth of 10 kilometers marked the boundary between the upper brittle crust, where fracturing produces earthquakes, and the hotter lower crust where earthquakes cannot occur. Fault ruptures often begin near this brittle-ductile transition zone, and it could serve as a cap for the rising fluids.

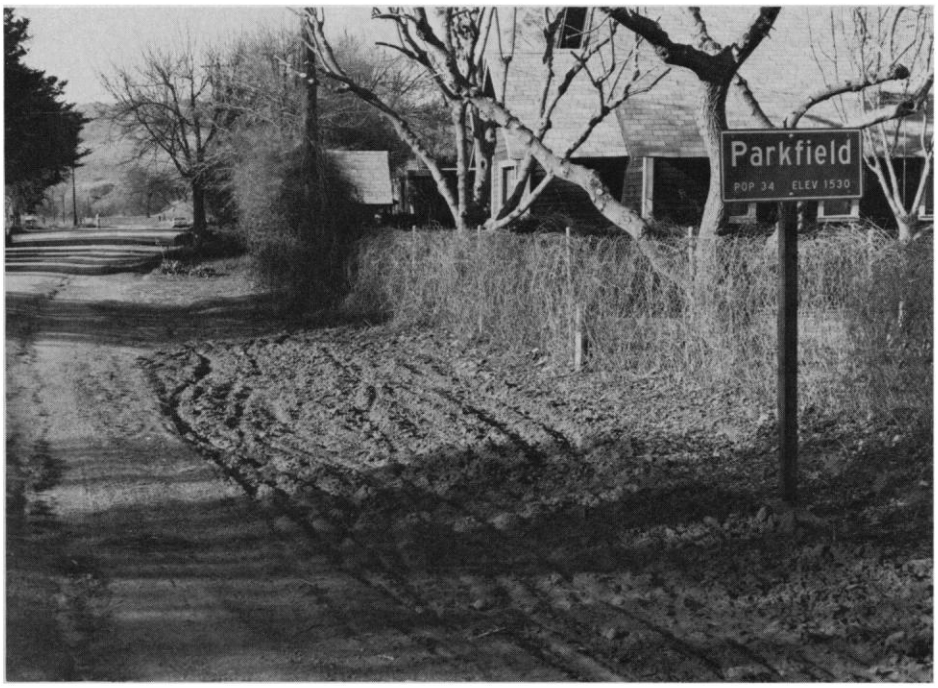
Once the fluid pressure rose high enough to counteract the squeeze on the fault, the otherwise insufficient stress tending to push the upper block up and over the lower block could drive a rupture. This is when the gold could begin to deposit. The upward propagation of the rupture into brittle crust would create an escape route and suddenly relieve the abnormally high pressure on the mineral-laden fluid, presumably encouraging the deposition of gold and other minerals. The deposition of carbon dioxide as carbonates is obvious in the Sigma Mine. Progressive mineral deposition fills and eventually seals the fractures through which fluids escaped, completing the cycle and setting the stage for the next pressurization.

Are faults that are today unfavorably oriented to driving stresses acting as valves that allow their periodic activation? Sibson cites as one possible example the magnitude 7.6 Kern County earthquake of 1952. When it struck on a high-angle fault during dry summer weather, stream gauges recorded a rapid surge in stream flow during 2 months that amounted to about 10 million cubic meters of water. Other types of faults that do not seem favorably oriented might also act as valves, although not as effectively as the ancient Canadian examples. These might include the San Andreas and very low angle faults in the Basin and Range of Nevada, says Sibson.

Waiting for Parkfield—No Precursors Recognized

This month is the midpoint of the 10-year interval in which an officially endorsed prediction calls for a moderate earthquake on the San Andreas fault near the tiny town of Parkfield in central California. Geophysicists are about as ready for that event as they ever will be. William Bakun of the USGS in Menlo Park, the chief scientist of the Parkfield Prediction Experiment, reported at the AGU meeting that more than 500 instruments of more than a dozen different types have been strewn across and around the 30-kilometer section of fault.

So far, no signs of an imminent earthquake have triggered a public warning under the alert procedures set up by the USGS and the State of California. The average



Downtown Parkfield, population 34.

interval between moderate Parkfield events is 22 years and the last event was 1966, so "we should be expecting another one," Bakun said, "but we see nothing now suggesting that the earthquake will strike at any particular time such as this January, this spring, or even during the rest of the year." Activity on the Parkfield section of the fault has triggered 61 D-level alerts and 14 C-level alerts during the past 2 years but no B-level alerts and none of the A-level alerts that would automatically trigger a public warning.

Not that things have been quiet around Parkfield lately. It is just that the alert procedures did not anticipate the kind of activity seen recently. Last September a swarm of microearthquakes of magnitude 1 to 2 struck near Middle Mountain, the point where ruptures of the Parkfield section begin. The swarm began on the 17th with five earthquakes within 7 minutes. According to Bakun, swarms are unusual near Parkfield and particularly so near Middle Mountain. In addition, creepmeters detected motion on the fault at three sites nearly simultaneously, something never seen anywhere in California before. "These two things really snapped us to attention," said Bakun, even though none of it fit any of the alert criteria developed from prior experience.

There are other curious goings on at Parkfield. After a post-September quiet, microearthquake activity picked up in November just north of Middle Mountain, which is the same area that saw a progression of larger, magnitude 2 to 3 events in the months before the 1966 Parkfield earthquake. And researchers have found a clock-like regularity in the changing water levels of a well on the flank of Middle Mountain. They began monitoring the well in late 1986 and soon noticed that sharp drops of about 12 centimeters accompanied by a millimeter of fault creep occurred every 90 days give or take a few days. Those monitoring the well successfully predicted the fourth drop of 1 November within 4 days.

This 90-day clock, which seems to reflect a seismic slipping deeper than a kilometer, joins an apparent clock that measures approximate 40-month intervals by ticking off small earthquakes 10 to 12 kilometers down on the fault near the initiation point of the 1966 rupture. This coming August the two clocks, if they are still keeping good time, should strike at much the same time. Whether that would trigger a moderate earthquake is anyone's guess.

As Wayne Thatcher of the USGS in Menlo Park noted, "We aren't at all sure that a C-, B-, or A-level alert will precede the earthquake; we don't know how to predict earthquakes." A prediction would be nice, he noted, but the primary purpose of the alert system is to ensure that researchers are closely following possibly significant developments. Although not perfect, the system seems to be working.

The Deepest Antarctic Ozone Hole Ever Seen

Researchers monitoring the annual thinning of the ozone layer over Antarctica reported at the AGU meeting that the ozone hole hit a record depth this October. The smallest amount of ozone detected during the month was 109 Dobson units, which represents a 50% decrease from the minimum of 225 Dobson units seen in 1979. The dramatic deepening of the hole apparently began around 1976. The new record is 20% lower than the previous one set in 1985 and is the lowest ozone amount ever observed anywhere.

Each October's hole may be deepening, but it is not widening to include any more of the globe. Arlin Krueger of the Goddard Space Flight Center in Greenbelt, Maryland, reported that the Total Ozone Mapping Spectrometer monitoring the hole from the Nimbus-7 satellite has detected no increase in the area of sharply decreasing ozone. Stratospheric ozone during October over such southern cities as Rio de Janeiro, Santiago, and Cape Town has decreased no more than 3 to 5% since 1979, which is in line with reported global declines. Only Punta Arenas, at the far southern tip of South America, seems to have felt the effect of the hole, the total ozone overlying it during October decreasing by 13% at most.

The hole's effects on humans at least would thus appear to be minor. Outside the hole, ozone decreases are small, and inside it the sun is still low on the horizon during October. John Frederick of the University of Chicago has calculated that even within the hole at McMurdo, half as much damaging ultraviolet reaches the ground than at Miami Beach on 21 June.

In another talk in the stratospheric ozone session, Margaret Tolbert and her colleagues at SRI International in Menlo Park reported on their recent laboratory results concerning the hole. Last fall's airborne expedition over Antarctica (*Science*, 9 October, p. 156) returned strong evidence that active forms of chlorine, ultimately derived from chlorofluorocarbons, were destroying ozone. There were also hints that the formation of stratospheric cloud particles and reactions on their surfaces led to the conversion of inactive chlorine to its active forms.

Tolbert confirmed the laboratory results recently reported in *Science* (27 November, p. 1253) by Mario Molina and his colleagues at the Jet Propulsion Laboratory showing that the postulated reactions do occur under Antarctic stratospheric conditions. Whether similar reactions accelerate ozone destruction under conditions more typical of the rest of the stratosphere remains to be seen. Molina did comment that the sudden deepening of the Antarctic hole in the late 1970s might have marked the attainment of a critical concentration of hydrochloric acid. ■ RICHARD A. KERR