small colony of *Callimico goeldii*, another endangered marmoset species, is being maintained at the Delta Regional Primate Research Center, Covington, Louisiana (R. Lorenz); a detailed studbook of this species is being compiled. A large colony of *Saguinus fuscicollis* and *S. nigricollis* has been maintained at the Lincoln Park Zoo, Chicago, Illinois (S. Kitchener). This colony of about 135 pairs has, since 1964, produced 1264 live offspring, most of which have been used for experimental purposes at Presbyterian–St. Luke's Hospital, Chicago. At the University of Texas Dental Science Institute at Houston, another large breeding colony of about 100 pairs of marmosets has produced about 1000 live young in a laboratory environment (S. H. Hampton). True second-generation breeding was reported in some species. There was tentative evidence that animals born in captivity have successfully bred and cared for their young only when they had remained with their parents as juveniles and had assisted in the rearing of their next-born siblings.

There was extended discussion of the advantages and disadvantages of a seminatural caging and feeding system, as opposed to the more regimented laboratory environment; both systems have produced some success in maintenance and breeding. Diets for the animals range from extensive feeding of live foods, fruits, and vegetables to complete maintenance for many years with only a commercial diet.

J. Wallach (Brookfield Zoological Park) stressed the need for more complete physiological and nutritional data about *Leontopithecus*, as well as about other marmosets and tamarins. Although the need for large amounts of vitamin D_3 in animals caged indoors is well known, other nutritional factors, especially the amount of protein intake, are often ignored. Not only is adequate medical care important in the maintenance of *Leontopithecus*, but detailed postmortem examinations are also essential.

The major recommendations of the conference include:

1) Although a studbook of the golden lion marmoset is currently being maintained, it was recommended that a much more detailed and extensive history of all captive *Leontopithecus* be compiled. A questionnaire that would provide this information was drafted; this would provide the most adequate basis to effect animal exchanges for increased breeding potential. It is hoped that all owners of golden lion marmosets in the United States, and perhaps in the world, will cooperate with efforts to compile a complete studbook of the golden lion marmoset. Computer facilities for processing, storage, and maintenance of this data have been obtained through U. S. Seal (Veterans Administration Hospital, Minneapolis, Minnesota).

2) Detailed standards for a model system for keeping *Leontopithecus* in captivity were drafted. The standards set by this model system should be followed by those institutions wishing to be designated as Golden Marmoset Breeding Centers approved by the Golden Marmoset Committee of WAPT. This system includes minimum and optimum standards of animal identification, record keeping and observations, medical care, nutrition, housing, social environment, maintenance and personnel, interinstitutional cooperation, and specifications for transport of animals between centers.

3) The conference sent a letter to the President of Brazil requesting favorable action in the creation of the Poco das Antas Biological Reserve. Because the survival of the golden lion marmoset in the wild seems to depend upon the immediate establishment of major habitat reserves, conference letters were also sent to the director general of the International Union for the Conservation of Nature requesting support for both the Tijuca Field Station and the establishment of the Poco das Antas Reserve. A similar appeal was forwarded to the president of the World Wildlife Fund.

4) A letter was drafted to be sent to all owners of golden lion marmosets describing the conference and its recommendations. It is essential that as many golden lion marmosets as possible be made available in a cooperative long-range breeding program. Some existing groups must be rearranged, new pairs formed, and further pairings made in the future.

It was the hope of the conference that its recommendations would result in positive actions to save the golden lion marmoset in the wild and in captivity. But there was also a greater hope—that this meeting would serve as an example of what could be done for other species facing extinction. The golden lion marmoset, because of its striking appearance, appeals to man; but there are many other species which, unfortunately, lack a golden coat but, nevertheless, are on the brink of extinction and would benefit from a like concern.

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Penrose Conference on Fracture Mechanics and Earthquake Source Mechanisms

Effective stress, stable sliding, stick-slip, stress drop, rupture velocity: these phrases are part of a new vocabulary in rock mechanics and seismology. How do they relate to earthquakes? Are there parameters whose measurement or observation might permit earthquake prediction? Where is the action today in understanding earthquake source mechanisms?

A Geological Society of America Penrose Conference, which convened at the Mountain Chalet, Snowmass-at-Aspen, Colorado, from 26 to 30 September 1971, fostered communication among rock mechanics experimentalists, dislocation theorists, earthquake engineers, and seismologists. Eighty-four experts heard 40 short papers in informal sessions on friction, pore pressure, microearthquakes, source mechanisms, and crustal deformation.

A major goal of the experimentalist is to apply to the earth what he finds in the laboratory; to make the results in hours and centimeters meaningful in terms of years and kilometers. In the laboratory, stable sliding or stick-slip (sudden rapid displacement) characterize movement in a friction experiment. By analogy, in the crust stable sliding accompanies a creeping fault without great seismic activity. On the other hand, stick-slip may describe behavior along seismogenic faults. High temperature, low effective pressure, high porosity, and thick gouge all enhance stable sliding in the laboratory and may also reduce or control the occurrence of major earthquakes on faults. Experiments also demonstrate that sliding friction does not depend on slip velocity and that static friction increases with the duration of the experiment.

Major contention arises, however, between geophysicists who believe that stable sliding is premonitory to catastrophic displacement and those who feel that creep and small earthquakes reduce the potential for large earthquakes along a fault. The first viewpoint derives largely from laboratory friction experience, whereas the second incorporates analyses of large crustal faults such as the San Andreas in California. Resolution of this debate is crucial to the interpretation of San Andreas behavior. In the language of rock mechanics, will stably sliding portions of the San Andreas abruptly switch to stick-slip? And how should one interpret "locked" regions of the great California fault? Has stress simply not reached a high enough level to initiate creep, or is it approaching a stage premonitory to catastrophic movement?

The most advanced line of inquiry into earthquake mechanisms involves the use of computers and laboratory rock mechanics data to develop models for quaking faults. Encouragingly, some models now realistically replicate fault behavior, complete with aftershocks and characterized by the motions and source parameters observed for natural quakes.

The presence, constitution, and mechanical behavior of fault gouge may be the most critical factors controlling the nature of fault displacement. Friction experiments with artificially prepared fault surfaces often neglect the complicating effects of comminuted debris along sliding planes. But gouge, usually in very thin layers, fills most fault zones. Studies of clay-rich gouge are important because of its complex compaction properties, which may be dependent on time or pressure. An improved comprehension of the mechanical properties of gouge is necessary for a sophisticated understanding of fault zone behavior.

The presence of water also plays a major role in fault motion. Water does not lubricate a fault, inasmuch as it does not alter friction coefficients. However, confined water does lower frictional resistance by reducing effective stress. That is, high internal pore pressure opposes and thereby diminishes the strengthening effect of confining or overburden pressure. The effects of water at depth may be more complicated because it becomes more active chemically, participating in hydration and dehydration reactions and hydrolytic softening of minerals.

Man inadvertently reduces effective stress with liquids through reservoir loading, injection in deep disposal wells, and secondary recovery methods, such as water flooding, in oil fields. Each of these has produced earthquakes. Increased seismic activity at the Rangely, Colorado, oil field correlates with waterflood injection. Water pressure exceeding hydrostatic triggers microearthquakes and provides an exceptional opportunity for understanding the earthquake mechanism. Using laboratory strength and friction data, together with in situ stress measurements, geophysicists can calculate the pore pressures necessary to "turn Rangely quakes off and on."

Excavation in deep mines, such as in the gold fields of South Africa, also provides a natural laboratory for making near-source measurements of small earthquakes and for perceiving the source mechanism itself. Mining at levels as deep as 3500 m often triggers earthquakes with Richter magnitudes as great as 4. Since energy changes during excavation are known, various seismic parameters can be measured with great accuracy.

Stress drop, seismic moment, apparent stress, and rupture velocity all pertain to the dynamics and geometry of a propagating seismic source. Theoretical models that incorporate laboratory fracture mechanics data are beginning to predict parameters close to those observed or calculated for real tremors. Dislocation theory provides the basis for most mathematical models of source mechanisms, but some of these require a deus ex machina to introduce fracture before propagation.

A major discrepancy between laboratory and field data concerns the magnitude of change in stress during an earthquake. Stress drops of only a few tens of bars accompany even very large tremors. On the other hand, stress drops in the kilobar range are frequent in laboratory stick-slip measurements. Explanations proposed to resolve the difference include fault plane irregularities which prevent 100 percent stress drop, self-sealing of the fault during propagation, low initial shear stress due to high pore pressure or low friction, or geometric effects such as might obtain along a long, thin fault.

Microearthquake analyses help to solve problems concerning major geologic crustal deformation as well as to elucidate the mechanics of seismic energy release. Familiar examples include tracing the intrusion path of magma along conduits in active Hawaiian volcanoes and delineating fault planes by location of aftershock focuses. In the case of the February 1971 San Fernando earthquake, aftershock focuses define a fault plane in the form of a north-dipping V, accompanied by surface breaks closing the open end of the V.

Microearthquake study also contributes to our understanding of plate tectonics and ocean floor spreading. Analyses of small earthquakes along a subduction zone under Alaska suggest that the down-going slab is not planar, inasmuch as microearthquakes concentrate along zones underlying topographic irregularities on the sea floor, perhaps reflecting bumps and hollows on the upper surface of the slab. However, in Alaska and Peru-Chile, repeat times for major earthquakes do not correspond with times estimated for plate motion; the recurrence time is too long by a factor of 2 to 4 in the Aleutians and too short by a factor of 2 to 3 in South America. In the western Pacific, seismologists have used laboratory friction experience to explain deformation behavior along inclined seismic zones. They model the earthquake mechanisms there with a spring-loaded block in frictional contact with an inclined plane. The static-to-dynamic ratio controls block motion.

A half-century of research provides support for a modified elastic-rebound theory for the origin of shallow earthquakes. But new evidence indicates that there is a need for additional insight into the mechanisms of aseismic slip and the roles of fault gouge and effective stress in controlling deformation mode. Also, if fracture mechanics explains shallow deformation accompanied by earthquakes, how does the behavior change with depth, where temperature and pressure may favor aseismic flow? The increasing correspondence between the models of source mechanisms refined by experiment and natural seismogenic deformation promises major breakthroughs for understanding this ancient affliction.

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