drilling program in the United States has not been started. The Carnegie Institution (Washington, D.C.) has just released a report that includes recommendations for such a program, to last ten years and cost over $110 million.

Key areas of investigation, the report says, are the active geophysical processes taking place in the continental crust and the crustal state and structure. Aside from the value of basic research in such a project, other implications are clear: It is hoped that the science of earthquake prediction and control would be advanced and that new geothermal resources could be tapped efficiently. It is also important to learn what effect this geothermal exploitation will have on the underground geothermal reservoir.

Most continental drilling in the US (especially deep drilling) has been done where an economic return was expected. More than two million holes have been made in the search for oil and additional ones made for ore deposits, but many areas of scientific interest have not been penetrated and even extant holes have not been optimally instrumented to collect geophysical data. This is not to say that existing holes cannot be used or extended, the report notes, but certain scientific questions can only be answered by drilling new holes in specific locations.

This drilling is proposed to be done in two phases; first, a series of many shallow holes (30 to 300 meters) followed by the selected drilling of intermediate and deep holes (300 to 9000 meters). The shallow-hole investigations together with regional studies of heat flow, thermal structure and state of stress in the crust could be started immediately at an annual cost of about $2 million. The bulk of the effort and cost, however, is associated with three main projects that need deep holes: the study of mechanism of faulting and earthquakes; hydrothermal systems and active magma chambers; and the extent, regional structure and evolution of the crystalline continental crust. Each of the three efforts would cost $20–30 million and take from four to seven years to complete.

Earthquake prediction and control can be implemented along an active zone such as those in California only after a more complete understanding of the earthquake mechanism is achieved. To do this, the report says, the physical properties of the rock at various depths near an active fault zone must be recorded *in situ* and knowledge of other parameters is also needed—measures of shear stresses, pore pressure, permeability and fluid chemistry. Many researchers believe that control of fluid pressure within several kilometers of a fault zone is the key to earthquake control and direct field measurements of rock permeability are necessary for this to be done.

Experimentally, these objectives can be reached by drilling at an appropriate site (such as the Bear Valley region of the San Andreas system) to depths of three, six and nine kilometers. The shallow hole would serve to monitor an area of low seismicity and low brittleness; the zone six kilometers down is the area of maximum earthquake frequency and probably dominated by brittle behavior; and at nine kilometers, the zone is largely aseismic, and the rock is characterized by ductile behavior. Drilling part of the way at a 45-deg angle will enable monitoring of both the rock adjacent to a fault and the material in the fault zone itself.

Hydrothermal magmatic systems. Great economic benefit can easily accompany scientific gains by drilling into and near hydrothermal and magmatic areas. Such zones fall into two categories—vapor-dominated (or dry-steam) systems and hot-water systems. Deep drilling will be necessary to determine if they are fundamentally different.

Geothermal energy (more easily extracted from vapor systems) and exploration for mineral deposits have their direct monetary payoff, but this type of drilling could have more profound ramifications—a sufficient gain in knowledge about magmatic systems could lead to predicting the time, location and violence of volcanic eruptions.

The experimental procedure for hydrothermal-magmatic system investigations would extend over a five to seven year period, involving geophysical reconnaissance to select appropriate sites and the various stages of drilling that extend into

- the shallow hydrothermal zone (⅓ to 3 km), the level of commercial drilling in recent years.
- deep hydrothermal or conductive-transfer zone (2–3 km), which is at the edge of the contact zone between the magma and the country rock. Almost nothing is known of this zone—its temperature and pressure gradients and fluid content.
- the magma chamber–country rock contact zone (3–6 km), where the temperature is 800–1000°C and major emphasis will be placed on *in situ* analysis of chemical gradients.
- the magma zone, should it prove to be feasible.

Major advances in drilling techniques and instrumentation are necessary for the hotter parts of the deep hydrothermal zone, and the layers below.

State and structure. Understanding the dynamics of plate movement is dependent on learning more about regional heat flow, the state of stress and the broad structure of the crust's crystalline basement. The analysis of stresses and forces will be much advanced, the report says, even with a modest drilling program. Also, data are needed to define the extent and nature of various heat provinces—now more possible because of the recently established relationship between heat flow and radioactive heat production in near-surface crystalline rocks.

Goals for this exploration include measuring spatial, time, temperature, pressure and chemical parameters of crustal evolution; defining of the external configuration and internal structure of the basement rock; investigating mechanisms of how basement rocks are formed and modified; and testing of models for the interactions between continental plate margins, and between oceanic plate margins and the continental crust.

The Carnegie report is an outgrowth of a workshop on continental drilling held during June 1974 at Abiquiu, New Mexico. The gathering was designed to provide recommendations for the US Geodynamics Committee, the group responsible for developing a US program for its participation in the 52-nation International Geodynamics Project (see PHYSICS TODAY, December 1973, page 19).

Satellite and observatory will study x-ray sources

A satellite launched in May and a new observatory at Kitt Peak, Arizona will provide astrophysicists with a dual means to observe x-ray sources. The satellite is Explorer 52, the third in the NASA Small Astronomy Satellite series; it has four experiments that make up a research package developed at MIT's Center for Space Research. The package includes

- a galactic absorption experiment, to monitor the absorption of low-energy diffuse x-ray background interstellar matter in the galaxy,
- a Scorpio monitor experiment, to view the time variations of x-ray activity in the x-ray source Sco X-1,
- a galactic monitor experiment, to help locate x-ray sources in the Milky Way to a precision of 15 arcsec and
- an extra-galactic experiment, which will monitor weak x-ray sources outside our galaxy.

The Earth-bound observatory to be used in conjunction with this satellite will be operated by scientists from the University of Michigan, Dartmouth and MIT. Money for the building was provided by McGraw-Hill Inc and the instrument housed therein is the 52-inch Cassegrain Coudé telescope, moved recently from the Michigan campus at Ann Arbor.

Data from the x-ray instruments on Explorer 52 will be radioed to Earth, analyzed and made available to astronomers at the McGraw-Hill Observatory. This will allow accurate optical observations of x-ray sources during periods of unusual activity.

Falling neutron

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given by $\beta = q_{\rm grav} \sin \phi$ where ϕ is the rotation angle and

$$q_{\rm grav} = 4\pi\lambda g h^{-2} M^2 d(d + a \cos\theta) \tan\theta$$

The neutron wavelength λ used was 1.445 Å, g is the acceleration due to gravity, h is Planck's constant, M is the neutron mass, and θ is the Bragg angle, 22.1 deg.

As the experimenters rotate the interferometer in the gravitational field, the potential Mgy (where y is the vertical height) in the Schrödinger equation, effectively changes the index of refraction of Schrödinger waves as a function of y. The neutron beam going uphill has its index of refraction increased. This changes the optical path. So as the interferometer is rotated, if the intensity at D moves up and down, one is presumably seeing the effect of gravity on the index of refraction of the neutrons.

The experimenters were delighted that the interference effect is big enough to see. Using their experimental parameters, the Purdue–Ford group calculated that they would see 19 fringes for a 180-deg. rotation, just about right for a convenient experiment. There wasn't much latitude in varying the parameters. If the neutron wavelength is increased, one no longer gets any Bragg reflection because the wavelength exceeds the lattice constant of the crystal. If the size of the interferometer is increased, the neutrons, as they fall in their parabolic path, will fail to Bragg reflect from the second slab because their angle of attack on the crystal will have changed. So in fact the experiment is limited to wavelengths less than 4 Å and crystals no larger than say 100 cm, Overhauser says.

To verify that the fringes they see are in fact due to quantum interference, the Purdue–Ford team first did their experiment with 0.71-Å x rays, which of course have no rest mass and therefore are practically not affected by the gravitational potential of the earth. Hence one would expect no change in the interference fringes as the crystal is rotated. In fact, however, the experimenters did see intensity variations because the interferometer itself was warping under its own weight and changing its orientation. Building an interferometer that will hold its shape rigid to 1 Å, Overhauser remarks, is "sort of like building an ordinary optical interferometer out of a blob of Jello. If you tried to rotate that, you can imagine what would happen."

The group had to find a method to mount the crystal so that the relative phase β is constant across the transverse dimensions (3 mm × 6 mm) of the interfering beams at D. Finally, after many months of effort, the experimenters found that they could get the best results with the crystal freely resting on two felt strips (3 mm wide and perpendicular to the axis of the cylindrical crystal). These strips were placed 15 mm from either end of a V block equal in length to the crystal. The rotation of the crystal was restricted to ±30 deg.

Significance. Observation of the fringes, Overhauser notes, proves that one needs a Newtonian gravitational potential in Schrödinger's equation. In other words, the gravitational potential coherently modifies the phase of the quantum-mechanical wave function. Furthermore, in their paper Colella, Overhauser and Werner say their experiment "provides the first verification of the principle of equivalence in the quantum limit." Elaborating on this point, Overhauser told us that he means they have tested the principle in a situation where the quantity being measured depends on Planck's constant in a way that cannot be eliminated.

The principle of equivalence says that one cannot tell the difference between doing an experiment in a gravitational field and doing it in a uniformly accelerating elevator. This implies that inertial mass is equivalent to gravitational mass. From the experiments of Galileo Galilei at Pisa to the more modern experiments by Roland von Eötvös and more recently by Robert Dicke and by Vladimir Braginski, the equivalence of gravitational and inertial mass has been well established.

In more recent times, the experiment done by Robert Pound (Harvard University) first with Glen Rebka (now at the University of Wyoming) and later with Joseph Snider (now at Oberlin College) verified the principle of equivalence for photons, the effect often called the gravitational redshift. That experiment verified that gravity affects matter of zero rest mass in the manner required by the principle of equivalence, Pound explains. In the Pound–Rebka–Snider experiment, the effect of gravity is made measurable by observing the change in a Mössbauer resonance when the source initially at the top of a building is moved to the bottom and the absorber at the bottom is moved to the top. In the process of falling in the gravitational field, the photons undergo a slight increase in frequency, Pound says. Overhauser argues that the Pound–Rebka–Snider result can be derived purely as a classical Doppler shift, and the derivation doesn't even involve Planck's constant.

The experiment done by Paul L. Richards (now at the University of California at Berkeley) and Philip Anderson (Bell Labs) ten years ago attempted to measure the quantum interference effect in superfluid helium (that is, the ac Josephson effect), in which the gravitational potential difference was provided by the difference in height between two reservoirs of liquid helium. In 1972 D. L. Musinski and David H. Douglass (University of Rochester) repeated the experiment and attributed the effect obtained by Richards and Anderson to something other than the Josephson effect. They and Isadore Rudnick (UCLA) argued that Richards and Anderson were observing an acoustic resonance. Richards and Anderson, on the other hand, believe that although subsequent experiments are all subject to this flaw, because they were done with a closed apparatus and fixed helium levels, their first attempt was not necessarily flawed, because the level was continuously changing. So they believe that their experiment might have been the first done on quantum interference due to a gravitational potential.

Anderson remarks that the Purdue–Ford experiment is analogous to the thought experiment proposed by David Bohm and Yakir Aharanov in the 1950's, which demonstrated the significance of the vector and scalar potentials. Both experiments involve the quantum interference of two beams. In the Bohm–Aharanov experiment, magnetic flux produces an electron phase shift. In the Colella–Overhauser–Werner experiment, the gravitational potential produces a neutron phase shift.

Other fundamental experiments in quantum mechanics are possible with the new neutron-interferometer technique. Werner, Overhauser and Colella, for example, are putting one neutron beam into a region with a magnetic field, which causes the spins to precess. If the precession is 360 deg, because the neutron is a spin-½ particle, the wave function changes sign. They hope to verify this theoretical property of spinors.

Other possible experiments were described to us by Clifford Shull, who together with Joseph Callerane, is currently building a neutron interferometer at MIT. One can polarize the two coherent components in the interferometer system. Then the polarization of one of the beams can be changed, and the two beams allowed to recombine with a change of polarization. Another possible experiment is to investigate how neutral the neutron is to greater precision than previously. Or, in the same vein, one can refine the limits on the electric dipole moment of the neutron. —GBL