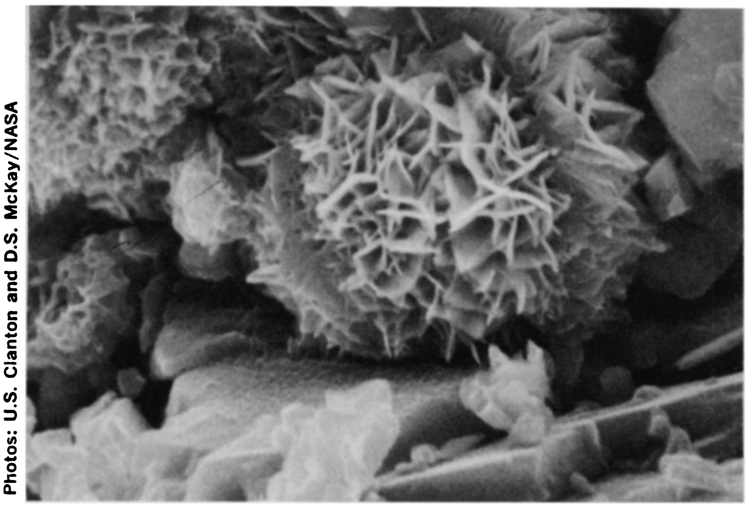
science news
OF THE WEEK

Lunar cataclysm(s)? A banged-up moon

Photos: U.S. Clanton and D.S. McKay/NASA



Rusty rock crystals: Iron and chlorine, but what else?

"It must in any event have been quite a show from the earth assuming you had a really good bunker to watch from." Gerald J. Wasserburg, March 1973.

The quest for the lunar Holy Grail—a whole moon rock 4.5 billion years old that has not gone through subsequent recrystallization—has come to a reluctant and temporary halt. At the Fourth Lunar Science Conference in Houston last week, Gerald J. Wasserburg of the California Institute of Technology presented age-dating results of highland material from Apollo 17 and Luna 20 samples and reiterated results from Apollos 14, 15 and 16. The various sites are widely scattered over the near side of the moon. The ages all appear to cluster in a several-hundred-million-year period around 3.9 billion years ago.

At that time the moon "really got clobbered," he says. This scenario has the moon very close to the earth and moving away through a tidal coupling. The moon plowed through numerous moonlets and an extraordinary amount of debris. This bombardment messed up and reset the radioactive clocks in the rocks. "If we didn't get hit, it must have been a hell of a good show to watch," he concludes.

There is an unresolved problem of how the earth-moon system stored this debris for 600 million years. But the problem is still there whether one posits a cataclysm or super-Imbrium event at 3.9 billion years or has the moon continuously or intermittently bombarded from the beginning up to a halt at 3.9 billion years.

John A. Wood of the Smithsonian Astrophysical Observatory has done a computer analysis of the moon's asymmetry that also implies a moon-clobbering period. He began the computer program to answer a plaguing question: Why is the moon so different, or asymmetric, in different places? Examples: The farside crust appears thicker than the nearside's. The far side is not covered with lava-filled basins as is the near side. The center of mass of the moon is about two or three kilometers closer to earth than the center of figure. The rocks high in uranium, thorium, potassium, phosphorus and rare-earth elements (KREEP) are concentrated in the western mare on the near side (although they do appear in lesser concentrations at all the sites).

Wood's hypothesis is that the moon was bombarded unevenly. When the moon was close to the earth (about three earth-radii), one side of the moon got hit more than twice as densely as the other side. The side that really got whacked is the leading edge or face of the moon that it presents as it goes around in orbit. The side the moon presents to the earth is determined by the distribution of mass in terms of the principal moments of inertia. Wood's program bombards the moon and redistributes the crustal material, then readjusts the moon's position periodically to keep what the moon would consider a stable orientation. In this view, the moon's orientation to the earth thus has evolved through a series of steps: bombing and then twisting, bombing and then twisting.

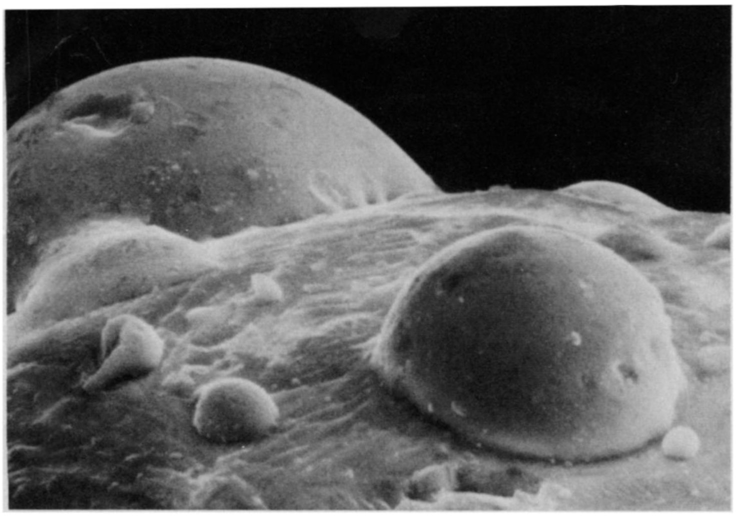
The thermal models for the moon's history are also in a continuous state of readjustment these days, as scientists seek an evolutionary model that can account for the present heat flow, the remnant magnetization, the extensive chemical differentiation seen in the rocks, and the seismic data. A picture emerges from work done by Paul W. Gast and David Strangway of the Johnson Space Center in Houston, M. Nafi Toksoz at Massachusetts Institute of Technology, the Caltech group, Gary Latham of University of Texas at Galveston, Ed Anders' group at the University of Chicago, Farouk El-Baz of the Smithsonian Institution, Marcus G. Langseth of Lamont Doherty Geological Observatory and Palmer Dyal of NASA's Ames Research Center.

Whether the moon accreted cold or hot (somewhere in the solar system) is still a puzzle. But what now appears certain is that before the extensive bombardment, the moon became hot and molten at the surface down to about 200 kilometers. At this time (between 4.3 billion and 4.5 billion years ago) the original crust formed. Crustal formation was followed by other extrusive activity in the highlands (since supposedly the lower regions or circular basins weren't created yet). This volcanic period produced basalt material rich in the KREEP and aluminum. Within this scenario, Gast and co-workers have four major groups of rocks: KREEP basalts; a newly recognized group of very high alumina basalts; anorthositic rocks with greater than 24 percent AL_2O_3, and then, later, mare and mare-like basalts.

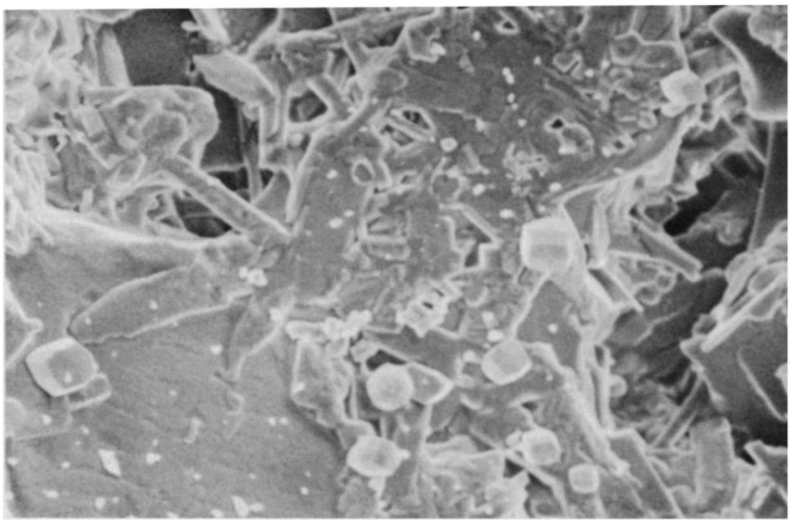
After the bombardment or whatever around 3.9 billion years ago that almost erased the original crust, the large basins were filled with material from below probably caused by internal melting. (The melting is probably caused by radioactive heating. Some of it is still going on; Langseth's second heat-flow probe gives about the same measurements as the flow at Apollo 15: about one-half the heat flow of the earth.) The period of mare-basin activity extended from about 3.8 or so billion years ago to 3.1 billion years. Wasserburg thinks that no significant, if any, activity has taken place in the last 3 billion years.

El-Baz and others, however, point to one unresolved question: regions on the near side that are overlaid by a darker mantling material that appears to be younger than the youngest maria dates of about 3.1 billion years. These areas form a large "ring of fire" analogous to the Pacific Ocean volcanic ring. The ring is located above the equator on the central-eastern side.

Interestingly for El-Baz's theory, within his ring of fire is one of two seismic belts located by Latham. The two belts do not connect. They overlay the 43 active zones of seismic activity. The quakes are occurring probably above a partially molten layer at depths of about 1,000 kilometers.



Orange glass: Tiny mounds grow on top of larger mound.



Iron crystals show new crystal habits in lunar material.

Another correlation is what appears to be an increase in volatile materials at sites within the ring of fire. These volatiles may point to volcanic fumarole activity. The orange glass of Apollo 17 is enriched in zinc, copper and gallium. Other odd-ball compositions appear at the Apollo 14, 16 and 17 sites.

New theories emerged to explain how the moon got magnetized (SN: 5/27/72, p. 346). Strangway has a "fence-riding proposal" that he offers if his favorite theory, an early lunar dynamo, proves unfeasible. It goes like this: While the moon was cold, it was exposed to a magnetic field of about 20 gauss and became magnetized throughout. The surface melting erased that magnetization, but the interior kept it and then remagnetized the surface lavas as they cooled. As the moon was bombarded, the more magnetized material from below was ejected all over the moon. This would explain why the magnetization appears random. Big magnetic anomalies appear in deep craters that may be filled with this ejecta. The highlands on the near side are more magnetic than the maria.

Dyal suggests the moon could have been magnetized by thermoelectric currents caused by the differences in material and temperature, perhaps when the surface was molten. To account for the observed field today, the magnetic people need only about 2 to 3 percent more iron than now appears in the moon, and the geochemical people indicate they would concede that. A figure for the moon's moment of inertia, presented by W. M. Kaula of the Jet Propulsion Laboratory, is 0.395, which allows for a somewhat denser interior (thus more iron) than was originally thought. □

A major surprise from CERN: Growth of proton cross section

Much of modern particle physics has been deduced from experiments in which beams of accelerated protons struck target protons. In the past year physicists have had a new energy range opened to them for proton-proton experiments—up to 400 billion electron-volts (400 GeV) at the National Accelerator Laboratory in Illinois and to the equivalent of thousands of GeV in the colliding proton beams of the Intersecting Storage Rings at the CERN Laboratory in Geneva.

The ISR has now served high-energy physicists with a sharp surprise. The surprise has to do with the total cross section for proton-proton collisions. The total cross section is the probability that anything at all will happen when projectile protons are fired at target protons. It is one of the most basic data in proton experiments. Up to now the total cross section had seemed to behave the way physicists believed it should: At low energies it is large. As the energy of the projectile proton increases, the total cross section decreases. Theorists believed that at sufficiently high energies this decrease would end, and the cross section would come asymptotically to a constant value.

The first experiments in the hundreds of GeV range seemed to bear out the prediction, and physicists rejoiced that they were entering a country where results were less dependent on energy and therefore simpler than at low energies. Two new experiments in the ISR, conducted by groups led by Giorgio Belletini of the University of Pisa and Giuseppe Cocconi of CERN, and reported last week, may end the rejoicing.

These measurements show that in the range of 1,000 GeV and up, the cross section increases, rising to the same range of values that it had at energies around 10 GeV and lower. This is contrary to expectation. The overall behavior of the cross section is thus that it decreases from zero to about 100 GeV, remains at a more or less constant minimum for several hundred GeV and then rises again.

The cross section is a geometric measure of probabality. It delimits more or less the space over which the proton's material influence is felt. Hit within that area and something will happen. The actual physical size of the proton is something different, but according to the CERN announcement a close idea of the actual size can be obtained by looking at how big a proton seems to another at just the grazing angle. Such measurements indicate that the diameter of the proton also rises slowly with energy.

One reaction has it that the ISR results will strengthen the hand of those theorists who believe in the parton model of the proton (SN: 10/28/72, p. 285). But the results seem bound to cause dismay elsewhere. According to the CERN announcement they cast doubt on one of the most strongly entrenched theories of particle physics, the so-called Pomeranchuk theorem.

The Pomeranchuk theorem is based on the symmetry of matter and antimatter. It says that although the proton-antiproton cross section can at low energies be a little larger than the proton-proton cross section, at high energies the two cross sections should tend to the same value. Unless the proton-antiproton cross section takes a sharp turn from its present direction somewhere between 70 and 300 GeV, it is likely to go below the proton-proton cross section. If it does, it will mean radical changes in physicists' beliefs about the relation of matter and antimatter.