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Scientists Find Deeper Meaning for Moon Rumblings

By KENNETH CHANG

In the category of "good research takes time," scientists have just discovered more than 100 quakes that occurred on the Moon three decades ago.

Seemingly combining archaeology and modern computer science, several groups of researchers have exhumed data from the Apollo landings and taken a closer look at them to improve their understanding of what the Moon is made of and why its inside trembles.

"It's a very exciting data set," said Dr. Yosio Nakamura, a geophysicist at the University of Texas who was among the scientists who analyzed the seismographs in the 1970's and continues to work on them today.

The lunar landers for Apollo 11 through 16 carried seismometers, the same type of instruments that measure earthquakes on Earth, designed to be left behind and to continue to radio back data after the astronauts left. Apollo 11 left a prototype that failed after a month, and Apollo 13, which was almost lost when its oxygen tank exploded, never made it to the lunar surface. But the four other seismometers, from Apollo 12, 14, 15 and 16, recorded some 12,500 seismic events through 1977, when NASA turned the network off.

As expected, the Moon shuddered when hit by small meteors. There were a handful of deliberate tremors when discarded parts of the Apollo spacecraft were sent crashing onto the lunar surface.

The seismometers also recorded 28 shallow "moonquakes" over eight years, the largest about magnitude 5.0. But more unexpected and still not well understood were numerous tiny moonquakes, several a day on average, that occurred far below, 500 to 750 miles down, about halfway to the Moon's center.

"That's deeper than any earthquake we see on the Earth," said Dr. Catherine L. Johnson, a geophysicist at the Scripps Institution of Oceanography in San Diego. "It tells you something about the ability of the middle of the Moon to fracture."

Nearly identical squiggles emerged from the Moon seismographs over and over, indicating that certain parts of the Moon's interior broke repeatedly in the same way, almost like someone cracking his knuckles. Dr. Nakamura and other scientists counted 108 of these regions, which they called nests. The rate of moonquakes seemed to ebb and flow on every 27 days, the time it takes the Moon to circle the Earth, suggesting that they were caused by the pull of tidal forces.

Almost all of the deep moonquakes originated on the near side of the Moon, the side that always faces the Earth. That meant either the structure of the far side is different and does not experience moonquakes or moonquakes do occur, but the waves dissipate when they hit a still molten core.

That was the unsatisfying, unresolved conclusion to Dr. Nakamura's initial studies 20 years ago. He also could not figure out the sources for more than 9,000 of 12,500 events in the seismographs at that time.

The difficulty then lay in the limits of early computers. The four seismometers on the Moon were advanced for their era, recording the data digitally and radioing the information to Earth in real time. But mainframe computers were incapable of processing that much data.

Instead, Dr. Nakamura and his colleagues took the computer-friendly digital data and printed them on old-fashioned rolls of paper, then placed the paper on light tables and identified moonquakes by eye. "We still have those pieces of paper," he said.

Now he has reanalyzed the 9,000 unidentified events using computers. In a paper published last month in The Journal of Geophysical Research, Dr. Nakamura reported that 5,885 of them turned out to be deep moonquakes and that he had located about 250 new nests. Only a few of the nests were located on the far side, leaving the question about the core and far side earthquakes still unanswered.

Meanwhile, Dr. Johnson and a graduate student, Renee C. Bulow, also sifted through the original digital seismic data, looking for the signatures of small moonquakes buried in the noise that may have escaped the attention of scientists looking at the paper printouts.

The largest of the moonquake nests in Dr. Nakamura's catalog had 323 events. In their analysis of that nest, Dr. Johnson and Ms. Bulow discovered an additional 101 moonquakes. Dr. Johnson estimated that when the entire analysis was complete, perhaps 1,500 new moonquakes would be added. The findings were reported at a meeting of the American Geophysical Union in December.

Another researcher, Dr. Amir Khan, a geophysicist at the University of Copenhagen, has also used modern analysis techniques on the moonquakes to conclude that the Moon's crust is about 25 miles thick, 25 percent thinner than earlier believed.

Based on the speed of the seismic waves, Dr. Khan concluded that the Moon's interior was considerably different from the Earth's upper mantle, with higher concentrations of aluminum and silicon and lower amounts of magnesium and iron.

That would fit current ideas that the Moon did not form at the same time as Earth. If that had been the case, the two bodies would be expected to have similar chemical make-up.

But even with computers wringing new answers from old data, the best hope for learning more about the Moon would be a new network of seismometers, especially on the far side.