to see this additional evidence of a tidal triggering mechanism, because a similar process appears to trigger terrestrial volcanic eruptions (*4*), and perhaps earthquakes as well (*5*). The terrestrial situation is somewhat obscured, however, because of the complicating loading effects of oceanic and atmospheric tides, ocean currents, and atmospheric circulation. The moon has provided another clear, albeit luxurious, view of the earth.

WAYNE L. HAMILTON
Institute of Polar Studies, Ohio State University, Columbus 43210

References and Notes

1. G. Latham, M. Ewing, J. Dorman, D. Lammlein, F. Press, N. Toksoz, G. Sutton, F. Duennebier, Y. Nakamura, *Science* **174**, 687 (1971).
2. P. Melchior, *The Earth Tides* (Pergamon, Oxford, 1966).
3. U.S. Naval Observatory, *The American Ephemeris and Nautical Almanac for the Year 1970* (U.S. Government Printing Office, Washington, D.C., 1968).
4. W. L. Hamilton, in preparation.
5. G. P. Tamrazyan, *Icarus* **9**, 574 (1968).
6. The suggestions of Paul Byard, Charles Corbató, and Henry Brecher are greatly appreciated. Contribution No. 221 of the Institute of Polar Studies, Ohio State University.

10 February 1972

Hamilton (*1*) has proposed that a combined latitudinal-anomalistic tidal triggering mechanism for moonquakes is supported by the data presented by Latham *et al.* (*2*). We agree that the anomalistic and the latitudinal tides are equally likely tidal triggering mechanisms (*1*), but, for reasons stated previously, we feel that the repeating moonquakes, designated category A, are primarily triggered by the anomalistic tide.

The identification of a particular tide as the primary triggering mechanism of category A moonquakes is based on the correlation between observed parameters, such as occurrence times of moonquakes and long-term variations in both moonquake occurrence times and energy release, and the theoretical variations in amplitude or phase (or both) of the suspected tidal component. Moonquakes should not necessarily be expected to coincide with maximum or minimum tidal amplitude, but they should occur with some consistent relationship to the amplitudes or phases (or both) of the triggering tidal component. Likewise, temporal changes in moonquake occurrence characteristics should be systematically related to changes in the triggering tide. If moonquakes represent shear dislocations along fault planes, the relative orientations of the fault planes and the principal tidal stresses would be a critical factor for the triggering of moonquakes. With no prior knowledge of the lunar global stress pattern or the orientations of the active faults, it is difficult to specify moonquake triggering mechanisms.

As shown by Latham *et al.* (*2*), category A moonquakes occur, with few exceptions, at monthly intervals near the time of perigee, with a secondary peak in activity near apogee. Category A perigee moonquakes account for over 95 percent of the category A moonquake energy observed at the Apollo 12 seismic station, with the largest subset, category A_1, accounting for about 80 percent of the total. The total monthly energy release varies with a period of 213 days, which agrees very well with the theoretical 7-month gravity cycle of the anomalistic tide. Also, the activity begins latest during months when the maximum energy is released. No effects of a latitudinal tidal triggering mechanism can be verified for the period 20 November 1969 to 1 January 1971 because the anomalistic and latitudinal tidal cycles were nearly in phase during that interval (*1*). A preliminary analysis of additional data has revealed that the largest category A moonquakes continue to occur near perigee through September 1971. These occurrence times correspond to about 6 to 7 days after the maximum northern latitudinal libration.

Thus, the data suggest that the category A moonquakes are primarily triggered by the anomalistic tide. The latitudinal tides may act as a secondary triggering mechanism. Such a "coupling" might better account for the observed variation in the category A total seismic energy release at perigee for the periods February to April and September to November 1970 (*2*) than does the influence of the solar tides, which is suggested by Hamilton (*1*), since the amplitude of the solar tidal component is only 1 to 3 percent of the amplitudes of the earth-generated tides (*3*).

A second type of moonquake, designated category B, has recently been identified (*4*). Preliminary data analysis suggests that the tidal triggering mechanism of category B moonquakes is different from that of category A moonquakes.

DAVID LAMMLEIN
JAMES DORMAN
GARY LATHAM
Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964

References and Notes

1. W. L. Hamilton, *Science* **176**, 1258 (1972).
2. G. Latham, M. Ewing, F. Press, G. Sutton, J. Dorman, Y. Nakamura, N. Toksoz, D. Lammlein, F. Duennebier, *ibid.* **174**, 687 (1971).
3. G. Sutton, N. Neidell, R. Kovach, *J. Geophys. Res.* **68**, 4261 (1963).
4. G. Latham, M. Ewing, F. Press, G. Sutton, J. Dorman, Y. Nakamura, N. Toksoz, D. Lammlein, F. Duennebier, in *Apollo 15 Preliminary Science Report* (NASA SP-289, 1972), section 8; in *Proceedings of the Lunar Science Institute Conference on Lunar Geophysics* (Lunar Science Institute, Houston, in press); in "Proceedings of the Third Lunar Science Conference," *Geochim. Cosmochim. Acta*, in press.
5. Supported by NASA contract NAS9-5957. The assistance of Lynn Sykes and Tosimatu Matumoto in critically reviewing the manuscript is gratefully ackowledged.

1 May 1972

Obsidian Hydration Dating Applied to Basaltic Volcanic Activity

Friedman (*1*) and Friedman and Smith (*2*) pioneered a valuable reconnaissance tool with their development of hydration-rind dating of obsidian, and Peterson and Groh (*3*) and Friedman and Peterson (*4*) made a good selection of an area in which to apply the technique when they chose Newberry Volcano, Oregon, with its variety of young volcanic rocks.

We have been involved in studies of Newberry Volcano during the past 5 years (*5–8*) and, thus, have special interest in the dating of these young volcanic rocks. Therefore, we feel compelled to point out that two of the reported dates are surely erroneous and to urge caution in the application of the hydration-rind technique to deposits that may have been subjected to hydrothermal or solfataric activity.

There are six young, rhyolitic obsidian flows in Newberry Caldera (*5*). Peterson and Groh (*3*) published hydration-rind ages for five of these flows and a ^{14}C age for charred tree wood from a pumice deposit that extends beneath one of the obsidian flows, commonly called the Big Obsidian flow. Their ^{14}C age agrees well with the hydration-rind age that they obtained for the Big Obsidian flow, and in light of relative ages based on geologic field relations, that age and the hydration-rind ages of three of the other obsidian flows as well, seem reasonable to us. However, the geologic relations and other ^{14}C ages indicate that Peterson and Groh's (*3*) hydration-rind age for the small obsidian flow in the crater of Central Pumice Cone (their Pumice Cone Crater Obsidian Dome) is greatly in error. This obsidian flow is in the bottom of the symmetrical crater of

Central Pumice Cone; it is a plug dome that rose in the vent of the pumice cone and then spread into a small flow. Thus, it must be younger than the eruptions that formed the crater in which it lies. These eruptions spread a thick layer of pumice and ash downwind to the east. Tree wood buried by this deposit has been dated by the ^{14}C method at 1720 ± 250 years by M. Rubin of the Geological Survey (*7*). The relative age of this deposit of pumice and ash is further confirmed by field relations and by other ^{14}C ages: it overlies an ash-flow deposit dated at 2054 ± 230 years by Peterson and Groh (*9*), but it is overlain by the Big Obsidian flow dated at 1270 ± 60 years (*3*). Clearly, the obsidian flow in the crater of Central Pumice Cone must be younger than 1970 years ($1720 + 250$), and its reported hydration-rind age of 5000 years (*3*) must be in error by approximately 60 percent. This is possibly due to the position of the obsidian flow directly over the vent where post-eruption vapors may have speeded hydration.

In their application of hydration-rind dating to basaltic rocks, Friedman and Peterson (*4*) obtained an age of 2900 ± 400 years for remelted rhyolite fragments in andesite extrusions (*8*) from East Lake fissure on the north wall of Newberry Caldera. However, the widespread ash and pumice deposit from nearby Central Pumice Cone does not mantle the fissure or the andesite spatter rim adjacent to it, although it covers older rocks on the caldera wall on either side of the fissure deposit. This indicates that the fissure eruptions are younger than 1970 years and that the hydration-rind age is in error by approximately 30 percent. Again, vapors rising through the fissure vent may have been the cause of this more rapid hydration.

We urge a thorough knowledge of the geologic relations before application of the new hydration-rind dating technique.

MICHAEL W. HIGGINS
U.S. Geological Survey, Beltsville, Maryland 20705
AARON C. WATERS
University of California, Santa Cruz

References and Notes

1. I. Friedman, *Science* **159**, 878 (1968).
2. ——— and R. L. Smith, *Amer. Antiquity* **25**, 476 (1960).
3. N. V. Peterson and E. A. Groh, *Ore Bin* **31**, 4 (1969).
4. I. Friedman and N. V. Peterson, *Science* **172**, 1028 (1971).
5. M. W. Higgins and A. C. Waters, *Ore Bin* **29**, 3 (1967).
6. A. C. Waters, *Moon Craters and Oregon Volcanos* (Univ. of Oregon Books, Eugene, 1967); M. W. Higgins and A. C. Waters, *Oreg. Dep. Geol. Miner. Ind. Bull. 62* (1968).
7. M. W. Higgins, *U.S. Geol. Surv. Prof. Pap. 650-D* (1969).
8. ——— and A. C. Waters, *Geol. Soc. Amer. Bull.* **81**, 9 (1970).
9. N. V. Peterson and E. A. Groh, Eds., *Oreg. Dep. Geol. Miner. Ind. Bull. 57* (1965).
10. Publication authorized by the director, U.S. Geological Survey.

28 February 1972

Since our original work on dating volcanic events in the Newberry craters (*1*), we have examined many hundreds of thin sections. The latest results reinforce most of our previous conclusions (*2*).

We do not believe that the fumarolic activity referred to by Higgins and Waters (*3*) has significantly influenced our results. If fumarolic activity had been a complicating factor, we should have found thicker hydration for samples from Big Obsidian flow, where the hydration thickness ranges from 0.9 to 1.1 μm. In addition, we should find a continuum of hydration thicknesses for samples that had different exposures to fumarolic activity. Instead, we find discrete thicknesses of hydration, corresponding to the discrete events that created the obsidian surfaces. Evidence of alteration is easily detected in thin sections, and such sections were rejected.

The Central Pumice Cone flows consist not only of a flow that plugs the vent and is now in the bottom of the symmetrical crater, but also of obsidian flows in the walls of the crater both above and below the vent. The results show consistently that the flows in the center of the cone have hydration thicknesses of 2.9 μm. Other flows in the Central Pumice Cone, particularly some later airfall material, have hydration rinds as thick as 3.6 μm. In our original publication (*1*), we used a hydration rate of 5 μm^2 per 1000 years. This rate was one that we had found for some archeological obsidian artifacts hydrating in southern Montana. In a more recent report (*4*), we used a hydration rate of 3 μm^2 per 1000 years, as derived from archeological material buried in southern Oregon. From temperature measurements which we are making on obsidian exposed to the atmosphere as well as obsidian buried in archeological context, it appears that the hydration rate is more rapid for exposed obsidian than for buried material. This is logical because the rate of hydration is quite temperature dependent, and exposed material is heated by the sun, which causes it to hydrate much more rapidly than buried material. The point at issue here is really the actual hydration rate rather than the influence of hydrothermal activity on the obsidian. As mentioned, hydrothermal alteration can easily be identified on these thin sections; where present, it has made measurement of the hydration thickness extremely difficult, and accordingly such sections have always been rejected. The consistency of the thicknesses of hydration on samples collected from various parts of a flow would rule out the influence of hydrothermal activity since it would not have acted uniformly on all specimens. The hydration rate of the exposed obsidian may be as high as 5 or 6 μm^2 per 1000 years. If so, the age discrepancies mentioned by Higgins and Waters disappear: if a rate of 5 μm^2 per 1000 years is used, the Central Pumice Cone flow would be about 1700 years old—the age that Higgins and Waters wish to assign to it. The East Lake fissure material also referred to by Higgins and Waters would then be of approximately the same age: its hydration thickness was 3 μm, and the rate of 5 μm^2 per 1000 years would give an age of 1800 years.

An alternative explanation of the age discrepancies may be found in the assignment by Higgins and Waters of the Central Pumice Cone vent as a source of the pumice eruptions 1700 years ago. But it should be pointed out that within 3 km of Central Pumice Cone there are at least four other vents, any one of which could have been the source of the pumice and ash. It is possible that the vent was in an area now covered by the Big Obsidian flow, which is less than 400 years old.

We think that much of this argument will be resolved when temperature measurements being made in the area allow us to calculate the rates of hydration of obsidian so as to date these flows more precisely.

IRVING FRIEDMAN
U.S. Geological Survey, Denver, Colorado 80225
NORMAN V. PETERSON
Oregon Department of Geology and Mineral Industries, Grants Pass 97526
EDWARD A. GROH
Oregon Department of Geology and Mineral Industries, Portland 97201

References

1. N. V. Peterson and E. A. Groh, *Ore Bin* **31**, 4 (1969).
2. I. Friedman, in preparation.
3. M. W. Higgins and A. C. Waters, *Science* **176**, 1259 (1972).
4. I. Friedman and N. V. Peterson, *ibid.* **172**, 1028 (1971).

17 April 1972