the sources. However, data on the energy dependence of the ratio $(17 \leqslant Z \leqslant 25)/(Fe + Ni)$ by Webber *et al.* (*3*) appears to indicate that this ratio decreases with increasing energy above 2 Gev per nucleon much more rapidly than the L/M ratio shown in Fig. 2. If this difference is upheld by future data, we shall be able to conclude that most of the cosmic ray fragmentation takes place in the sources and not in the interstellar medium. We should note, however, that in this case the cosmic rays should sample a sufficiently low average density in the interstellar medium. This could be achieved if cosmic rays preferentially avoid interstellar clouds.

Consider now in Fig. 1 the proton spectrum above 50 Gev and the alpha particle spectrum above 10 Gev per nucleon. The maximum-likelihood method yielded spectral indices of 2.75 ± 0.03 and 2.77 ± 0.05 for protons and alphas, respectively (*14*). As discussed above, however, the medium spectrum with index 2.64 fits both the protons and alphas below 50 Gev per nucleon. Thus, there seems to be evidence for a steepening of the proton and alpha particle spectra. A consequence of our model is a similar steepening in the spectra of all nuclei with $Z \leqslant 14$. This spectral change beyond about 50 Gev per nucleon could be due to propagation effects in the interstellar and interplanetary mediums, or it could be produced in the sources. Observations may differentiate between these two possibilities: the spectrum of iron should steepen above 50 Gev per nucleon if we are observing a propagation effect; it should remain the same as below 50 Gev per nucleon if the steepening is produced in the sources of the nuclei with $Z \leqslant 14$. It should be noted that if iron is accelerated at the surfaces of neutron stars, its spectrum may have a different high-energy cutoff due to photonuclear disintegration (*15*). The cutoff energy, however, depends greatly on the pulsar model, and no firm predictions can be made.

Our final prediction with the present model concerns very very heavy (VVH) nuclei (*16*). Since these nuclei are believed to be produced by neutron capture processes and probably are not present on neutron star surfaces, they should not be generically related to iron nuclei. Their spectrum should therefore differ from the spectrum of iron.

In summary, we find that the increase of the ratio of iron nuclei to medium nuclei with increasing energy cannot be easily explained by propagation effects alone, and it appears to require an additional source or acceleration mechanism for iron at high energies. On the basis of a model in which iron comes from a different source than the rest of the primary cosmic rays, we have made predictions of several observable effects. It is hoped that future high-energy cosmic ray experiments, such as those planned for the high-energy astronomical observatory satellite of the National Aeronautics and Space Administration (*17*), can make these observations.

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Obsidian Hydration Dates Glacial Loading?

Abstract. *Three different groups of hydration rinds have been measured on thin sections of obsidian from Obsidian Cliff, Yellowstone National Park, Wyoming. The average thickness of the thickest (oldest) group of hydration rinds is 16.3 micrometers and can be related to the original emplacement of the flow 176,000 years ago (potassium-argon age). In addition to these original surfaces, most thin sections show cracks and surfaces which have average hydration rind thicknesses of 14.5 and 7.9 micrometers. These later two hydration rinds compare closely in thickness with those on obsidian pebbles in the Bull Lake and Pinedale terminal moraines in the West Yellowstone Basin, which are 14 to 15 and 7 to 8 micrometers thick, respectively. The later cracks are thought to have been formed by glacial loading during the Bull Lake and Pinedale glaciations, when an estimated 800 meters of ice covered the Obsidian Cliff flow.*

The thickness of hydration rinds on the surface of obsidian (volcanic glass of rhyolitic composition) increases with age and has been used for dating obsidian artifacts that were manufactured 200 to 250,000 years ago (*1*). Hydration rinds have also been used to measure the age of rhyolite volcanic flows (*2*).

The hydration-rind dating method is based on the ability of a fresh surface of obsidian to adsorb water from the air or soil, and the ability of this adsorbed water to then slowly diffuse into the body of the obsidian at a rate which is dependent mainly on temperature and somewhat on the composition of the glass, but which is independent of humidity. The diffusion front is sharp and can be recognized by the abrupt change in refractive index at the hydration interface (*3*). A preliminary experimental measurement of the rate of hydration as a function of temperature was published by Friedman *et al.* (*3*). Additional experimental work gives a more precise temperature-rate relation, and shows that the rate of hydration increases as a logarithmic function of temperature (*4*).

From measurements made thus far and also from data on archeological material, the thickness of the hydration rind increases linearly with the square root of time:

$$\text{thickness} = \text{constant (time)}^{1/2}$$

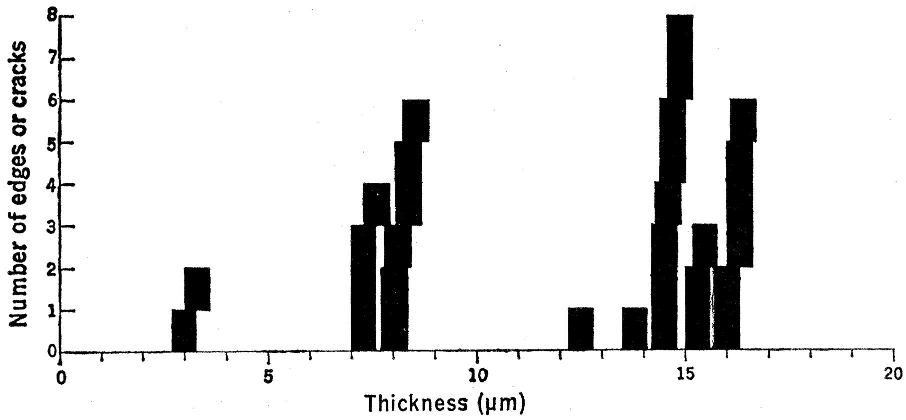

Fig. 1. Thicknesses of hydration rinds on surfaces and cracks in the Obsidian Cliff flow. The replication error is plotted as ± 0.3 μm to encompass easily measured as well as less distinct rinds.

In an attempt to relate hydration thicknesses on a rhyolite flow containing obsidian to the age of the flow as determined by the K-Ar method, we examined a number of samples of obsidian collected in a small cavelike structure in the face of Obsidian Cliff, Yellowstone National Park, Wyoming, about 30 m below the flow surface.

Thin sections of the samples showed that many contained surfaces and cracks which have hydration rinds of differing thicknesses (*5*). The data given in Table 1 and illustrated in Fig. 1 indicate that surfaces and cracks show a definite grouping of hydration thicknesses.

We relate the thickest of a group of hydration rinds, 16.3 μm thick (average), to the time of original emplacement of the flow, which has recently been dated by the K-Ar method at 176,000 ± 6,000 years (*6*). This gives an average hydration rate of 1.5 μm^2 per 1000 years, which is compatible with calculated rates based on measured ground temperatures. The actual rate probably was somewhat slower during glacial maxima when the area was covered by ice, and faster during interglacial climatic warming (*7*).

Applying this average rate to the cracks with rind thicknesses of 14.5 and 7.9 μm gives ages of 140,000 and 40,000 years, respectively. If we assign an error to the hydration ages of ± 20 percent, encompassing all the uncertainties in the actual (rather than average) hydration rate as well as the uncertainty in the K-Ar age, we calculate ages in the intervals from about 110,000 to 170,000 and 30,000 to 50,000 years ago.

In searching for likely events that would have caused widespread cracking of the obsidian at these two times, we are struck with the fact that the thicknesses of the hydration rinds correlate with the thicknesses of rinds on glacially abraded obsidian pebbles from Pinedale moraines (7 to 8 μm) and from Bull Lake moraines (14 to 15 μm) in the West Yellowstone Basin. These are the terminal moraines for glaciers at the axis of an ice cap located right above the Obsidain Cliff flow.

Pierce (*8*) estimates that the ice thickness above Obsidian Cliff at the maximum of the Pinedale Glaciation was about 800 m. For the Bull Lake maximum he postulates a similar but slightly thinner ice cap above the Obsidian Cliff flow, although south of the Obsidian Cliff flow the Bull Lake ice cap was probably thicker than the Pinedale one.

Table 1. Thicknesses of hydration rinds associated with surfaces or cracks, measured on thin sections. A prime on a slide number indicates that the slide was made from the same obsidian sample as the slide in the row above. Replicate measurements on a typical slide agree to ± 0.2 μm.

Slide	Hydration rind thickness (μm)
1	14.5
2	7.3, 14.5
2′	7.3, 16.0
3	7.3, 14.5
4	16.4
5	8.4
6	14.6, 15.3
7	8.2, 14.7, 15.3
8	3.3, 12.5
8′	14.7
9	14.9
9′	8.1, 16.3
10	16.3
11	7.6, 13.8, 15.5, 16.3
12	16.0
13	8.1, 8.6
14	8.4, ~14.8
15	3.0

We think it most reasonable that the cracking of the obsidian occurred as loading increased. Cracking may have occurred during the entire ice buildup in Bull Lake time, and during the second (Pinedale) loading only when the maximum Bull Lake loading was approached or exceeded.

An age of about 40,000 ± 10,000 years for the maxima of the Pinedale (Wisconsin) Glaciation falls in the middle of the Wisconsin time interval, considerably earlier than the midcontinental late Wisconsin maximum. An age of 140,000 ± 30,000 years for Bull Lake is greater than previous estimates of the age of Bull Lake and will be discussed separately by Pierce *et al.* (*7*).

The occurrence of cracks in obsidian specimens that have different hydration thicknesses has been noted before in samples from Newberry Craters, Oregon. The multiple cracks in the Oregon samples seem to be related to subsequent eruptive events occurring in the immediate vicinity (within 1 to 3 km) (*9*). This explanation for the multiple cracking events cannot be applied to Obsidian Cliff, inasmuch as no eruptive centers of these ages are known within 40 km of the Obsidian Cliff flow and inasmuch as centers 20 km away that erupted about 87,000 and 108,000 years ago do not have cracks correlative to those in the Obsidian Cliff flow.

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