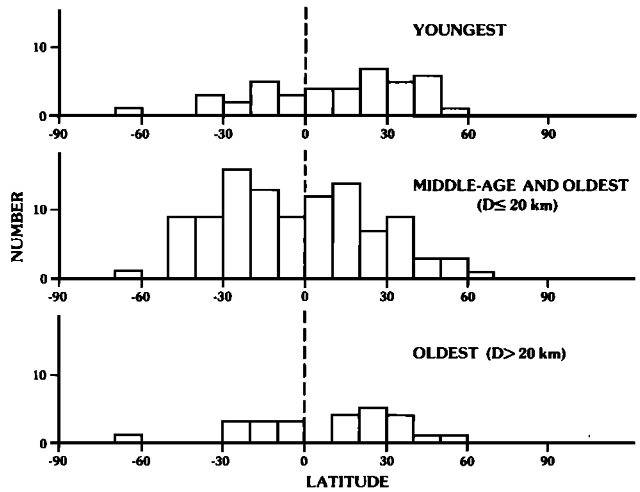

Fig. 5. Histogram of three combined age classes as a function of latitude. Class 4 and 5 craters with maximum diameter smaller than 20 km have been grouped with Class 3. Latitudinal dependence reflects the effect of polar deposits and processes that mask potential candidates.

(mean diameter of 10 km) on the lunar maria that would fit the selection criteria used for the identification of martian grazers. This is approximately what might be expected for the number of impacts (about one event equal to or larger than 3 km) on all the lunar maria (6.4 × $10^6 km^2$) with impact angles less than 5°. The limited resolution for Mercury introduces a severe selection bias and similar comparisons are not possible with great confidence.

The second difficulty with attributing Mars grazers to heliocentric objects is the change in impact directions with time. Mars-crossing asteroids perturbed from the asteroid belt dominate the martian cratering record [*Wetherill,* 1975]. Such objects would have relatively low inclinations (<25°) to the ecliptic. One can imagine a set of circumstances wherein east-west impact directions might be recorded on Mars. First, if we assume that the obliquity of Mars is small (<10°) and that the encounter velocities are large relative to the velocity of Mars in its orbit, then at any given time grazing impacts in the polar regions would tend to be in a northerly or southerly direction while the only possible grazers near the equator would be in an east-west direction. As Mars rotates over a 24 hour period, grazers at the pole would randomize while grazers near the equator would continue to be parallel to the equator. Such conditions also would permit a larger number of grazers per unit area at the pole than at the equator owing to the continuous exposure of the pole to impactors from 360° directions during a 24-hour period in contrast with a very restricted exposure (<5°) near the equator. This effect was pointed out in *Gault and Wedekind* [1978] for the moon.

However, several circumstances alter such an idealized case for Mars. First, the gravity of Mars deflects the path of an incoming object such that a grazer near the pole could impact at lower latitudes. The degree of deflection depends on the relative velocity, however, and only relative encounter velocities less than about 5 km/s would result in significant deflections [*Öpik,* 1976]. Second, if the Mars-crossing objects represent asteroids perturbed from the orbits in the asteroid belt, then prograde asteroids will have encounter velocities sufficiently small that the direction of impact, as seen from Mars, will not appear to be in the plane of the ecliptic. The net result will be randomized impact directions, even though the orbits may have low inclinations. Third, the obliquity of Mars is not small and changes periodically, with values ranging from 10° to 45° (the present value being 23°) as discussed in *Ward et al.* [1979]. This change in obliquity changes the idealized geometry described above, thereby randomizing any preferred impact direction.

One last scenario could be devised where the oblique impacts represent ricocheted remnants or tidally disrupted fragments from a single heliocentric object. Laboratory experiments [*Gault and Wedekind,* 1978] show that high velocity impacts result in fragmented down-range ricocheted debris. Fragmentation should be more severe at broader scales, thereby reducing the size of any down-range debris such that only very small craters would be produced. Although a tidally disrupted asteroid could produce a family of grazers with similar impact directions, the morphologic ages of observed craters in each class span a large range. It is doubtful that they all could be assigned to a single event; nevertheless, such a process can produce groups of impacts with similar orientations.

Origin by Areocentric Impactors

Three observations favor an origin by satellites whose orbits tidally decayed with time. First, the most recent grazers have impact directions in a generally east-west direction with

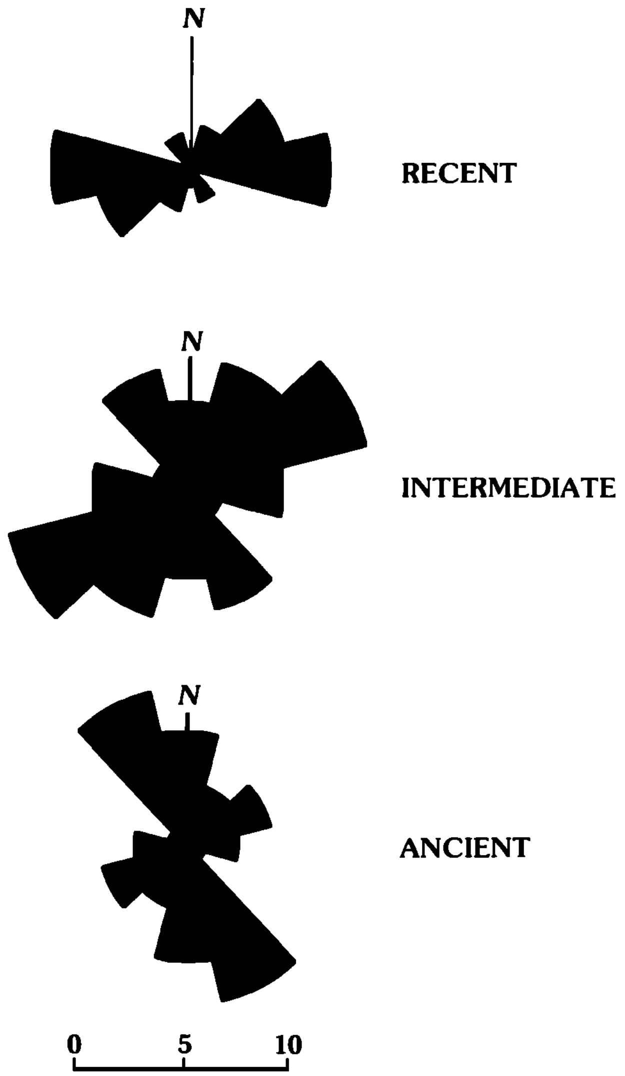

Fig. 6. Rose diagrams comparing impact directions for different relative age classes. Impact directions appear to become more northerly with increasing age.