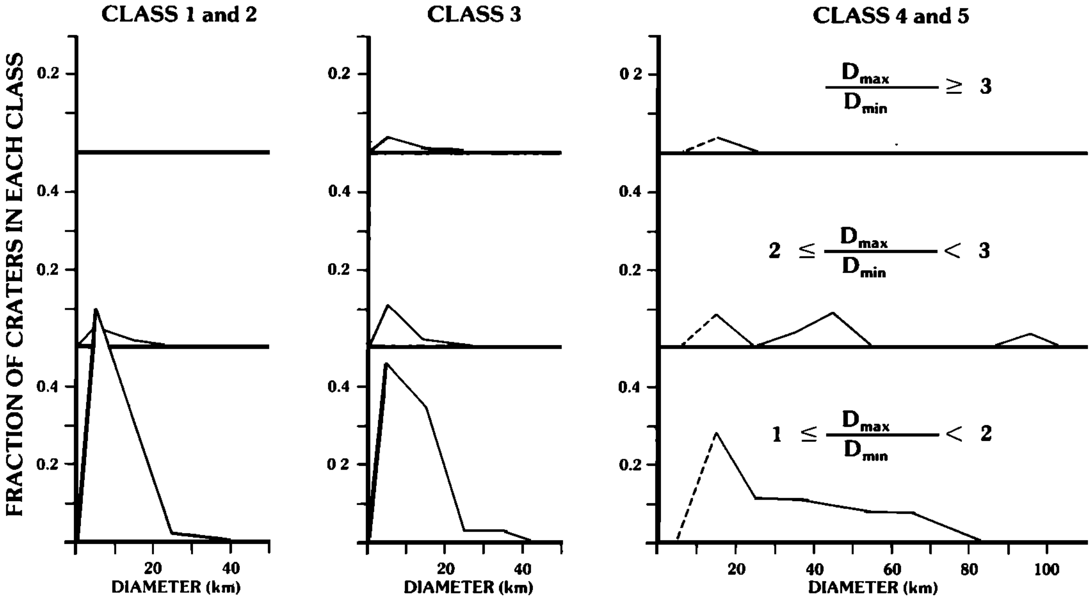

Fig. 4. Histograms of the ratio of maximum and minimum crater diameters for each crater age class. Ratios have been combined for D_{max}/D_{min} equal to or greater than 3, between 2 and 3, and between 1 and 2. Larger and older craters, in general, tend to be more elongated.

observational bias producing such a trend since the selection criteria for the oldest craters relies heavily on the crater shape and morphology, rather than ejecta facies.

Most of the selected craters occur within ±50° of the present martian equator, as shown in Figure 5. There are two principal reasons for such a trend. First, very active erosional and depositional processes in the polar regions effectively mask craters. Second, craters with relative ages equal to or greater than three cannot occur, by definition, on young geologic units. Because significant portions of the northern part of Mars represent relatively young plains and because the southern portions are occupied by the active gradational provinces of the Argyre and Hellas Basins, there is a paucity of older examples selected from the far northern and southern latitudes.

The orientations of the major diameters for each class of grazers are shown in Figure 6. The rose diagrams confirm the general observation, which stimulated this study and which is illustrated in Figure 2, that the direction of impact changes from east-west for the younger age class to north-south for the older age classes. Such rose diagrams, however, hide any systematic changes with latitude or longitude, and a method to reveal such changes is described in a later section.

DISCUSSION

The data for Mars-grazing impacts provide two general and intriguing results. First, there appears to be a large number of grazing impacts on Mars relative to the moon. Second, the direction of impact appears to change with time: from east-west at present to near north-south at times comparable to and before the major epochs of plains volcanism. Mars-grazing impactors have two obvious origins: heliocentric (asteroids and comets) or areocentric (martian satellites) objects. The following discussions focus on these two provenances and consider their likelihood in terms of the observations.

Origin by Heliocentric Impactors

Mars-crossing asteroids and comets are unlikely sources for the population of grazing-impact craters selected in this study for two principal reasons. First, the number of grazers relative to nongrazers per unit area on Mars is significantly greater than the number on the moon. If the probability of a grazing impact by heliocentric-orbiting bodies is about the same for these two planets, then the martian impacts more likely resulted from Mars-orbiting objects. Second, Mars-crossing asteroids or comets should produce random impact directions over long periods of time, owing to the randomizing effects of relative collision paths, gravity deflection, and changes in the martian obliquity.

The probability of impact at angles smaller than a given angle (i) for a gravitating body is simply $\sin^2 i$ [*Shoemaker*, 1962]. Thus 25% of the craters should have formed with angles less than 30° and only 0.7% wih angles less than 5°. Laboratory experiments [*Gault and Wedekind*, 1978] indicate that the butterfly pattern and crater elongation do not become pronounced until the impact angle becomes less than about 5°. If we assume that these results scale to larger impactors, then the angles of impacts for the craters selected in this study were probably less than 5°, thereby representing only 0.7% of the crater population.

The number of Mars-grazing impacts must be corrected for selection effects due to areal coverage, identification limitations, and inferred age of the surface. The number of identified grazers larger than 5 km on the ridged plains of Lunae Planum is approximately 5% ±0.4% of the total crater population larger than 5 km. Similar results were obtained for Syrtis Major Planitia (3% ±0.5%) with slightly higher values for the cratered plains near Uranius Tholus (8% ±0.4%). Thus there appears to be about an order-of-magnitude excess in Mars grazers relative to theoretical predictions for an isotropic flux of impactors. Figure 7 shows the cumulative frequency distribution for grazers equal to or younger than Class 3 occurring on the ridged plains units of Lunae, Sinai, Solis, and Syrtis Major. Between 8 and 11 km the slope of the power-law decay is about -2.3 but between 11 and 20 km it is about -1.5. A similar transition in slopes is observed in the general crater distributions on the martian plains but occurs at around 1 km [*Neukum and Wise*, 1976]. For comparison, Messier is perhaps the only crater larger than 5 km