The origin of grooves and crater chains of Phobos

J.B. Murray, D.A. Rothery & G. Thornhill, Dept. of Earth Sciences, The Open University, Milton Keynes MK7 6AA, England,
J.-P. Muller, T. Cook, T. Day & J. C. Iliffe, Dept. of Photogrammetry & Surveying, University College London, Gower Street, London WC1E 6BT, England

Nearly all explanations so far proposed for the origin of grooves and crater chains on Phobos have fundamental objections to them. The theories may be broadly divided into (1) effects of tidal or drag forces and (2) effects consequent upon the formation of Stickney, the largest crater on Phobos. The well-established characteristics of grooves and crater chains may be summarized as follows:

A. Most crater chains strongly resemble secondary impact craters in their morphology.
B. Groove and chain configurations consist of the intersections of planes with the surface of Phobos.
C. Individual chains and grooves are nearly always members of a family of chains, sometimes consisting of several dozen members, which have plane intersections almost exactly parallel to each other.
D. The central (often hypothetical) member of each family (i.e. the one following a great circle) nearly always passes through the leading apex of Phobos (0° lat., 90° long.); thus virtually all chain families appear parallel along the sub-Mars and anti-Mars meridian.
E. There is a zone with no crater chains or grooves centred at the trailing apex of Mars (i.e. 0° lat., 270° long.).
F. Crater chains and grooves are younger than the large (above about 2 km diameter) impact craters on Phobos.
G. Groove families are of different ages, one set consistently cutting another where relationships are clear.
H. Crater chains near Stickney overlie it, indicating that they are younger than Stickney.

The recently developed software capable of deriving digital elevation models automatically by both photogrammetry (1) and photoclinometry (2) has been applied to Phobos and has established the following:

I. Virtually all chain craters and grooves have rims raised above the surrounding terrain.
J. Near the ends of groove families, "shadow zones" can occur where grooves disappear on slopes facing towards the groove end, and reappear again on slopes facing away from the groove end.
K. One groove cuts a crater within (i.e. younger than) Stickney itself, indicating that at least one chain is probably very much younger than Stickney.

An example of observation (I) is shown in fig. 1. This shows clearly that the main 50m deep groove of coalesced craters running across the map has a raised rim on both sides, rising several metres above the surroundings. These are critical observations, indicating that grooves are morphometrically indistinguishable from secondary impact craters.

The suggestion (3) that the grooves and crater chains of Phobos might be secondary craters from large, probably basin-sized impacts on Mars seems to have been ignored, yet this explanation fits all the above observations, and predicts exactly the pattern of grooves and crater chains observed. Phobos, by far the closest to its primary of all the satellites in the solar system, can be hit from any direction by ejecta from Martian impacts. Even the anti-Mars point can be reached by ejecta in an elliptical orbit on its return journey to Mars. Primary impact velocities into Mars up to well over 40 km s⁻¹ are expected, from which about 3% of ejected matter is capable of attaining speeds of 4 km s⁻¹ or above (4), the minimum ejection velocity required to reach Phobos. Such ejecta is expected to consist of clots of highly shocked, fractured and partially melted rock, whose initial velocity rapidly declines as crater excavation progresses. This means that a mass of ejected clots will be steadily stretched out in a direction radial to the crater, as the leading clots at higher velocity draw away from the following ones. Ejecta from the impact will thus ultimately consist of strings of ejecta clots radial to the impact site.

If Phobos were to encounter these ejecta strings, then a large number of virtually parallel chains of impact craters would be formed on Phobos. Each chain within a family will follow the intersection of a plane cutting Phobos; and provided that each ejectum in a string has followed the same orbit, the chains
will be parallel to Phobos orbit, i.e. the plane passing through the centre of Phobos should also pass through the leading and trailing apex. Later impacts on Mars would create further families of parallel chains of craters. The central member of each family could cross Phobos' 0° or 180° meridian at any latitude depending upon the ejecta orbit, but should always pass through the leading apex of Phobos.

If the ejecta velocity at Phobos is always less than Phobos' orbital velocity, then there should be a "zone of avoidance", where no grooves or crater chains occur, centred around the trailing apex of Phobos. The measured Phobocentric angular distance from the end of the central member of a groove family to the trailing apex can be used to determine the minimum velocity of ejection from Mars, and the maximum velocity of the ejecta hitting Phobos, assuming that Phobos was at today's distance from Mars at the time of impact.

Groove and crater chain families from several different Martian impacts have been identified, for which minimum ejection velocities from Mars between 4.03 and 4.45 km s⁻¹ have been derived, and maximum impact velocities at Phobos of 0.37 to 1.91 km s⁻¹. Of these Martian impacts, two have given rise to particularly dense groove families, and we suppose that these result from large, basin-sized impacts. One of these families, because of its singular inclination, should have come from an impact in a high northern latitude on Mars if Phobos had been in its present orbit at the time of impact. In view of the fact that there are no large basins visible in high northern latitudes (though one could have been buried beneath the polar cap or the wind deposits around it), the orbit of Phobos may have changed from a high to a low inclination since the large basins were formed.

However, the configuration of the grooves and crater chains implies that Phobos must already have been in orbit round Mars, with the same synchronous rotation and orientation to today, at the time of the intense bombardment of Mars around 4000 million years ago. The absence of chains and grooves on Deimos could be due either to its having been being captured more recently, or to the fact that it was far enough away from Mars to escape the worst of the ejecta bombardment that its closer companion received.

REFERENCES:


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