



Fig. 8. (a) Approximately concentric troughs and scarps surrounding the higher albedo central palimpsest of Valhalla, on Callisto. (Voyager 1 image 16421.51, centered near  $16^{\circ}\text{S}, 46^{\circ}\text{W}$ .) (b) High-resolution images of scarps in the Valhalla structure. Intermediate-albedo material extends from the bases of the scarps and buries the eastern halves of the crater rims marked by the arrows. (Voyager 1 image 16424.46, centered near  $60^{\circ}\text{N}, 37^{\circ}\text{W}$ .)

orientation between the largest dark terrain areas, but the overall concentric configuration does break down in two types of smaller dark terrain regions, (1) in small dark polygons located along a possible younger zone of left-lateral shear, which could have been rotated or fractured during motion along the shear zone early in grooved terrain formation (arrows, Figure 9), and (2) in regions  $\geq 3000$  km from the center of furrow curvature, most notably "Eastern Barnard Regio" and eastern Nicholson Regio. In addition to these arcuate furrows, system III also contains a smaller number of furrows 150-500 km in length that are arranged subradially to the center of arcuate furrow curvature (Figure 9). Where they occur as discrete features the subradial furrows are usually superposed on the arcuate ones. However, several furrows in "Eastern Barnard Regio" take  $90^{\circ}$  turns and have arcuate or radial orientations in different portions of their traces, suggesting that formation of the arcuate and subradial furrows was at least partly contemporaneous. Notably, there is a complete lack of both ridges and any other possibly compressional features throughout system III.

Previous studies of this furrow system have yielded differing interpretations of whether furrows in "system III" actually belong to one system or two. *Schenk and McKinnon* [1987] calculated poles of concentricity for the arcuate furrows in Perrine Regio and for those in Barnard Regio and Nicholson Regio that are east of  $0^{\circ}\text{W}$ . They found different centers of curvature and suggested that the furrows form two sets, one arranged concentric to  $38^{\circ}\text{N}, 32^{\circ}\text{W}$  (observed in Barnard and Nicholson Regio) and a superposed set in Perrine Regio arranged concentric to  $56^{\circ}\text{N}, 46^{\circ}\text{W}$ . *Murchie and Head* [1986, 1988] also measured poles of concentricity for furrows in Barnard Regio and Nicholson Regio, and they included in the

measurements furrows as far west as  $30^{\circ}\text{W}$ . They found different centers of curvature in the two regions, neither of which is close to the center of curvature of the furrows in Perrine Regio. They interpreted the arcuate furrows to belong to a single system arranged crudely concentric to  $60^{\circ}\text{N}, 50^{\circ}\text{W}$ , whose concentricity breaks down in its distal portions (one-third to one-half the distance to the antipode) where furrow trends were highly influenced by preexisting structures [cf. *Schenk and McKinnon*, 1987]. The latter interpretation is more consistent with the lack of discontinuities in furrow orientation or major geologic boundaries between Perrine Regio and Barnard Regio.

Two large surface units can be defined in the sub-Jovian hemisphere on the basis of morphology and albedo: (1) "Eastern Barnard Regio" and southeastern Nicholson Regio (Figures 10a and 10b), and (2) Barnard Regio and northwestern Nicholson Regio (Figures 10c and 10d). In "Eastern Barnard Regio" and southeastern Nicholson Regio the furrows have widths of 10 km or more, irregular to scalloped walls, and in some cases raised rims. Furrows are superposed on several large craters which retain significant topographic relief (e.g., left arrow, Figure 10b). In Barnard Regio and northwestern Nicholson Regio furrows are generally narrower than in the other surface unit, with widths of about 6 km [*Croft and Goudreau*, 1987]. They also typically have more linear walls, and they crosscut only a few very flattened craters (e.g., arrow, Figure 10d). Photometric studies by *Helpenstein* [1986] also indicate that the surfaces of Barnard Regio and northwestern Nicholson Regio have a higher albedo than do surfaces of the other unit.

Both surface units of sub-Jovian dark terrain exhibit a complex age relation of furrows and dark material deposits. Southeastern Nicholson Regio and "Eastern Barnard Regio"