GEOLOGIC MAP OF THE PERRINE (Jg-2) AND NUN SULCI (Jg-5) QUADRANGLES OF GANYMEDE

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DESCRIPTION OF MAP UNITS

LIGHT MATERIALS

ls **Smooth material**—High albedo. Surfaces smooth and grooves generally absent. *Interpretation:* Dominantly ice magmatically emplace on or adjacent to dark materials

lg **Grooved material**—Medium to high albedo. Grooves either subparallel or radiating; surface between grooves has smooth texture. Sparsely cratered. *Interpretation:* Similar to smooth material. Grooves due to extensional faulting

lgi **Irregularly grooved material**—Similar to grooved light material except grooves not parallel or grouped in sets. Density of grooves highly varied. Includes small areas of grooveless light material. *Interpretation:* Similar to smooth material

l **Undivided material**—High albedo. Surfaces appear smooth. *Interpretation:* Light materials whose distinguishing details cannot be resolved because of poor image resolution

lt **Transitional material**—Intermediate in albedo between other light materials and lightest dark material; texture varied. *Interpretation:* Dark material covered by thin veneer of light material or possibly by polar frost

DARK MATERIALS

dg **Grooved material**—Surface texture lineated; average albedo slightly higher than for cratered dark material; streaked appearance in detail. *Interpretation:* Cratered dark material structurally modified by grooves. Darkest grooves also may contain younger deposits

df **Furrowed material**—Albedo like that of grooved material: abundant superposed furrows. *Interpretation:* Cratered dark material structurally modified by furrows

dc **Cratered material**—Surface texture rough. Average albedo low, but unit appears mottled, patchy, or streaked. Craters of all sizes common. *Interpretation:* Mixture of ice and silicates

d **Undivided material**—In generally small patches. Smooth-appearing; no resolvable surface detail. *Interpretation:* Dark materials whose distinguishing details cannot be resolved because of poor image resolution or small size of exposure

CRATER AND PALIMPSEST MATERIALS

[Only craters and palimpsests greater than 15 km in diameter are mapped. They are interpreted to be formed by impact]

c_3 **Material of bright craters**—Rim crests are sharp and complete, ejecta blankets well preserved, and albedo high; craters generally have associated bright rays

c_2 **Material of somewhat degraded craters**—Rim crests well defined and complete; ejecta blankets subdued or incomplete. Albedo distinctly lower than that of bright craters. Common central peaks

c_1 **Material of highly degraded craters**—Only rim segments remain except at crater Sati, which also retains mappable ejecta

cs **Material of secondary craters**—Clusters or chains of small, oval craters inferred to be secondaries

p **Palimpsest material**—Relatively bright, generally subcircular patches inferred to be scars of relaxed craters

INTRODUCTION

Ganymede is the third of the four Galilean satellites of Jupiter. It is also the largest (radius of 2,631 km). Models for the interior structure that are constrained by distance from the Sun and a mean specific gravity of 1.93 indicate that about half of Ganymede's mass consists of water ices (Cassen and others, 1982). Spectral and photometric properties suggest that perhaps as much as 90 percent of Ganymede's surface is water ice (Pilcher and others, 1972); the remainder is inferred to be silicates (Pollack and others, 1978; Sill and Clark, 1982; Clark and others, 1986).

Although the surface of Ganymede exhibits many complex details, it can, to first order, be divided into two general types of terrains on the basis of average albedo (Smith and others, 1979a,b; Squyres and Veverka, 1981; Helfenstein and others, 1984). The albedo difference is believed related to the proportion of silicates mixed with the ice. Light terrain is generally riven by abundant long, narrow grooves. Dark terrain is generally more heavily cratered than light terrain and much less commonly cut by grooves.

The map area is in the sub-Jupiter hemisphere of Ganymede. All images used for mapping were obtained by Voyager 1. The terminator was located at about long 305° when the images were obtained, and all coverage in Jg–2 west of about long 60° was obtained with emission angles too large to produce images usable for mapping. Resolution of the primary mapping images ranges from 2.4 to 5.2 km/line pair; images covering Jg–5 are generally superior to those covering Jg–2 (see resolution diagram). The mapped part of Jg–2 is about equally divided between light and dark material, whereas the mapped part of Jg–5 comprises approximately 25 percent dark material and 75 percent light material. An intermediate-albedo transitional unit occurs locally; this unit is grouped with light materials.

STRATIGRAPHY

The dark and light materials are placed in a time-stratigraphic sequence primarily by means of embayment and crosscutting relations. The density of impact craters also is an indicator of relative age, and dark materials are generally more heavily cratered and thus older than light materials. However, within the two groups, crater densities are generally not reliable indicators of relative age, because all materials contain too few craters to determine statistically meaningful age differences.

Crater and palimpsest units range from material that is highly degraded (palimpsest) to very fresh (craters having bright rays). This classification is inferred to correspond approximately to a relative-age sequence. Caution is necessay, however, because of size-dependent effects on degradation: (1) micrometeorite bombardment, favoring survival of large craters, and (2) viscous relaxation, favoring survival of small craters. Nevertheless, if very large and very small craters and palimpsests are ignored, one can infer with reasonable confidence that morphologically degraded craters are older than fresh craters.

DARK MATERIALS

The oldest and most widespread dark material is cratered material. Although the average albedo is relatively low, in detail this material appears patchy, streaked, or mottled, because its surface is a montage of high- and low-albedo areas at scales of a few to tens of kilometers. In places, this appearance seems caused by grooves or fragments of crater rims that are too small to map, but generally the surface characteristics responsible cannot be identified. The surface texture is rough at a scale similar to or smaller than that of the albedo variations. Craters of all ages and all sizes, from the limits of resolution to the largest in the mapped area, are superposed. Individual grooves and troughs are locally present, many of which crosscut or coincide with contacts between light and dark materials.

Furrowed dark material occurs only in the northern part of the subrounded, western part of Perrine Regio in Jg–2; the material is part of one of the furrowed dark-terrain groups defined by Murchie and Head (1988). The albedo of the furrowed material is generally higher than that of cratered dark material, possibly because the abundant furrows commonly have bright margins (Guest and others, 1988). Similar densities of superposed impact craters indicate no difference in age between furrowed and cratered dark materials; the furrowed unit very likely is cratered material that has been tectonically modified by the furrows.

Grooved dark material occurs generally in small areas adjacent to larger areas of cratered dark material, commonly along their contacts with light materials. The average albedo is somewhat higher than for cratered dark material, and in detail the surface has a streaked appearance consistent with the orientations of lineaments or grooves. In many places, the grooves are clearly continuous with grooves in adjacent light materials; hence, the grooves represent a relatively young structural modification of cratered dark material. Grooved dark material here includes what has been mapped as lineated dark material in other quadrangles of this series, because image quality does not permit separation into two map units.

Undivided dark material is mapped where neither structural features nor craters can be resolved. Its generally smooth appearance and uniform, low albedo are most likely due to poor resolution.

LIGHT MATERIALS

The largest area of transitional material is in the northern part of Jg–2. The unit is probably dark material covered by a thin veneer of light material or blanketed by the polar frost caps. These caps apparently are thin deposits of water frost that cover the surface of Ganymede down to a latitude of 40° to 50° in both hemispheres. The caps may be either (1) the remnants of a formerly more extensive frost blanket that has been removed from lower latitudes by sublimation, or (2) an accumulation of frost that has built up over time by transport from lower latitudes (Purves and Pilcher, 1980).

Light grooved material is perhaps the most distinctive geologic unit on the satellite. It is characterized by very regular patterns of grooves transecting the surface. The grooves are curvilinear depressions as much as a few kilometers wide, a few hundred meters deep, and hundreds of kilometers long (Shoemaker and others, 1982). Unfortunately, the resolution of the best images is insufficient to reveal details of the geometry of the grooves, but they appear to be roughtly U-shaped in cross section. Groove slopes are gentle; at Voyager resolution, typical slopes are less than 10° (Squyres, 1981). The grooves are arranged in subparallel or fan-shaped groupings called sets. The sets intersect and crosscut one another with a geometry that is locally very complex. The range in morphology from one groove set to another is considerable: in some sets the grooves are packed closely together, producing roughly sinusoidal topographic profiles, while in others they are widely separated by distinct smooth areas. Within sets, spacings between adjacent grooves range from about 4 to 17 km, with a mean of about 8 km (Grimm and Squyres, 1985). Where the smooth areas are extensive, they are considered to be a separate unit, smooth material.

Irregularly grooved material shares several characteristics with grooved material: it has low crater density and fairly high albedo, and its surface is dominated by grooves. Tlhe distinction is that the grooves are not arranged in sets. Instead, they can have a variety of complex geometries. Individual grooves may be straight, arcuate, or sinusoidal, but the trends of adjacent grooves are not correlated as they are for grooves that are arranged in sets. Individual grooves may crosscut and truncate one another, and they may split or merge at acute angles, forming a crudely anastomosing pattern.

Smooth material is similar in albedo to most other light materials, but it is distinguished by a paucity of grooves and subdued topography at the best available image resolution. In particular, we observe no flow fronts or other features that might provide morphologic clues to the emplacement mechanism. Albedo is commonly fairly uniform across individual areas of smooth material. Some exposures, however, appear mottled, suggesting local variations in silicate content. Smooth material is seen in a variety of geometric relations with other light units: it occurs as irregularly shaped, groove-free patches in areas that are otherwise dominated by a complex pattern of grooves, and it also forms long, curvilinear swaths whose geometry is similar to that of groove sets; some swaths are bounded by grooves. Smooth swaths and other exposures commonly have sharp boundaries with all other units. Locally, however, boundaries are indistinct, and smooth material is transitional to dark or other light materials.

Undivided light material has an albedo similar to that of other light materials, but it is observed at an image resolution, viewing geometry, or illumination geometry that prevents the recognition of characteristics that would identify it as one of the other light units. It is mapped primarily in the poorly imaged central portion of Jg–2.

CRATER AND PALIMPSEST MATERIALS

Overall, the most degraded crater structures mapped on Ganymede are the palimpsests (Passey and Shoemaker, 1982)—roughly circular areas that are smoother and generally brighter than their surroundings. Their contacts are not sharply defined. Most palimpsests mapped on Ganymede are older than light materials, but the larger of the two palimpsests mapped in Jg–5 is an exception; it overlies the light materials and is therefore younger. It forms a distinct dome, rising more that 2 km above the surrounding plains (Squyres, 1981). Its topography is roughly concentric and gently undulatory except for a smooth central region about 60 km across (mapped as smooth light material). No vestige of the original crater morphology is preserved, but its well-developed field of secondary craters (unmapped) clearly shows an impact origin. Palimpsests have been suggested to form when viscous subsurface material is extruded in response to an impact (Thomas and Squyres, 1990), and this palimpsest may be a particularly late and massive example of such an extrusion.

Highly degraded craters (unit c_1) are generally only rim remnants. An exception is the 95-km-diameter, two-ringed crater Sati in Jg–2. Because both of its rings are incomplete, this crater is classified as highly degraded even though mappable ejecta are present, which is very likely due to the large size of this feature. The ejecta blanket is clearly truncated by light grooved material, indicating that Sati is older.

Somewhat degraded craters (unit c_2) are the most abundant class. Many have central peaks or pits, and most retain at least some mappable ejecta. In general, ejecta limits are difficult to map because the contacts with surrounding materials are gradational, and the albedo and texture of the underlying light or dark materials show through. Somewhat degraded craters are present on both dark and light materials, but superposition relations indicate that some of these craters are clearly older than light materials.

Most bright craters (unit c_3) have extensive bright rays, and generally their ejecta completely mask the albedo and texture of older underlying materials. Bright crater ejecta are everywhere younger than both light and dark materials.

The floors of large craters of all types are bowed upward, providing evidence of some viscous relaxation of their topography (Johnson and McGetchin, 1973; Parmentier and Head, 1981; Passey and Shoemaker, 1982).

Mappable secondary craters are present locally in small clusters or chains. No source crater has been identified for any of these secondary craters, but they are presumed to be relatively young because of their small size and fresh appearance.

STRUCTURAL GEOLOGY

Grooves are the dominant structural features on Ganymede. While single grooves are found in many areas, they are more commonly grouped in sets with common structural trends. Many grooves in sets are nearly parallel, but fan-shaped sets also are observed. Groove spacing can differ substantially from one groove set to another, but within a given set the spacing tends to be more nearly constant. Sets may intersect in complex crosscutting relationships; the central region of Jg–5 is one of the most complicated on Ganymede in this regard. Where one groove set crosscuts another, no trace of the cut groove set is generally observed within the crosscutting set. One of the few exceptions is seen at lat 40° N., long 314°. The boundaries of groove sets are in places marked by particularly long and deep grooves, and the boundary between light and dark materials is commonly marked by a parallel single groove or groove set in the light material.

Ganymede's grooves are generally thought to be extensional features (Smith and others, 1979a,b; Squyres, 1980; Parmentier and others, 1982, Squyres, 1982; Golombek and Banerdt, 1986). They could plausibly have formed as a result of global expansion (Squyres, 1980; Shoemaker and others, 1982), although expansion would have been somewhat limited (McKinnon, 1981). Thermal stresses (Zuber and Parmentier, 1984) and convective stresses (Squyres and Croft, 1986) may also have played a significant role in groove formation. The subsurface geometry and origin of grooves cannot be determined from Voyager images, however. The grooves appear to be grabens, but the images are insufficiently resolved to rule out the possibility that they are modified extension fractures or some kind of ductile necking features. The interpretation of grooves (and groove sets) as extensional features leads to the use of relative-age criteria similar to those generally inferred for truncating relations among sets of rock joints of Earth, as discussed by Golombek and Allison (1981).

Some direct but sparse evidence for structural shear in the map region is seen where groove sets appear to be offset by several tens of kilometers along narrow shear zones (Lucchita, 1980). Compelling evidence for compression is scarce, although the feature at lat 40° N., long 314° cited above appears to possess parallel ridges rather than grooves, and thus it could be compressional.

GEOLOGIC HISTORY

Crater densities within the cratered dark material—the oldest unit in the map area—are consistent with an age on the order of several billion years (Smith and others, 1979b). Thus, cratered dark material is probably crust that has survived from the end of the Solar System's primordial intense bombardment. The other dark materials most likely are cratered dark material that has been tectonically modified by furrows or grooves, and the materials are probably the same age as dark cratered material.

After formation and cratering of the dark materials, the crust was fractured and dismembered, and light materials were emplaced between or on top of the surviving crustal fragments. The process of emplacement is inferred to be extrusion of magmas relatively rich in ice (for example, Parmentier and others, 1982). The thickness of the light materials in the map area is unknown, but in other parts of Ganymede it has been estimated at 1 to 2 km (Schenk and McKinnon, 1985). The light materials were then extensively stretched, resulting in the intricate pattern of grooves that characterizes much of the light terrain in these quadrangles. Complex crosscutting and truncation relations indicate that the grooves were formed over a protracted period, which almost certainly overlapped in time with the extrusion of ice-rich magmas. Futhermore, in some places clear truncation relations indicate that smooth light material is younger than the grooves in adjacent grooved light and dark materials, indicating that ice volcanism continued after local cessation of groove formation.

Impacts occurred throughout the time of emplacement of light and dark materials. The oldest impact structure in the map area is probably the partial palimpsest at lat 29° N., long 356°. Highly degraded craters (unit c1) are younger than some cratered dark material and perhaps younger than furrowed and grooved dark materials; these craters may once have existed on the furrowed and grooved materials but later were modified structurally so that they are unrecognizable on the available images.

Most of the abundant somewhat degraded craters (unit c2) are younger than all light materials except possibly smooth light material, but a few appear to be older than all light materials. The large palimpsest at lat 30° N., long 335° is probably the same age as somewhat degraded craters. Bright craters (unit c3) appear younger than all light and dark units.

This brief history is almost certainly greatly oversimplified as a result of the poor resolution and unfavorable viewing geometry of most the images covering the two quadrangles. Textural features that are just at the resolution limit of the best images suggest that a much more complex history can be inferred when better images are returned by future missions.

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