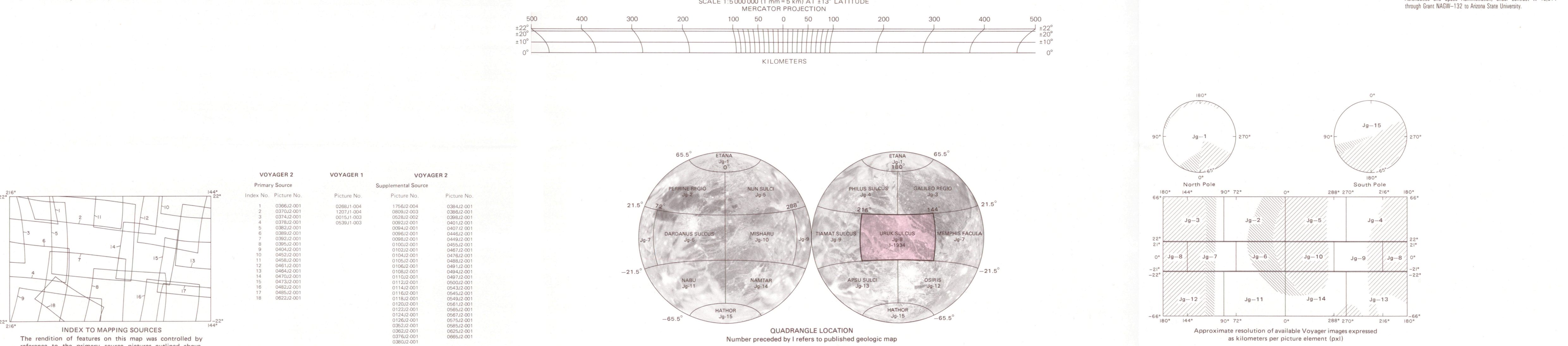


Base from U.S. Geological Survey, 1984. Shaded relief and surface markings of the Uruk Sulcus quadrangle of Ganymede. U.S. Geological Survey Miscellaneous Investigations Series Map 1-1598

Prepared on behalf of the Planetary Geology and Geophysics Program,
Planetary Division, Office of Space Science and Applications, National
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INDEX TO MAPPING SOURCES
The rendition of features on this map was controlled by reference to the primary source pictures outlined above. Supplemental source images used during the compilation are listed separately. Copies of various enlargements of these pictures are available from National Space Science Data Center, Code 601, Goddard Space Flight Center, Greenbelt, MD 20771.

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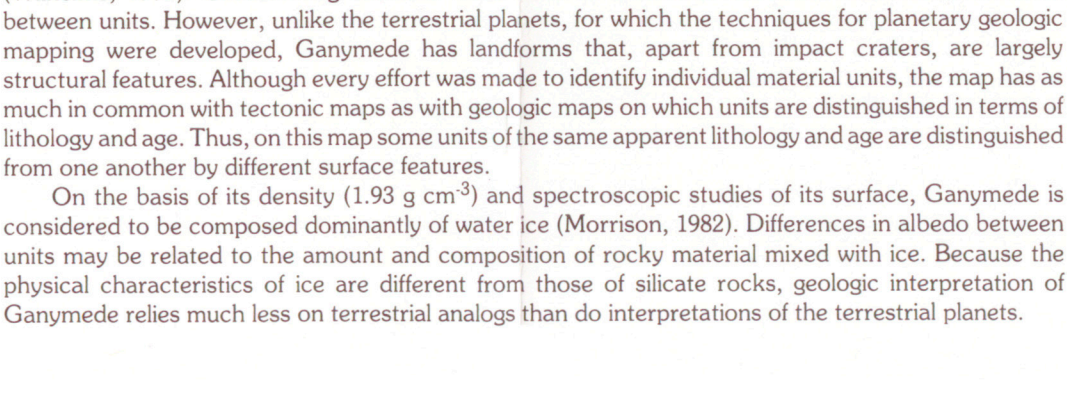
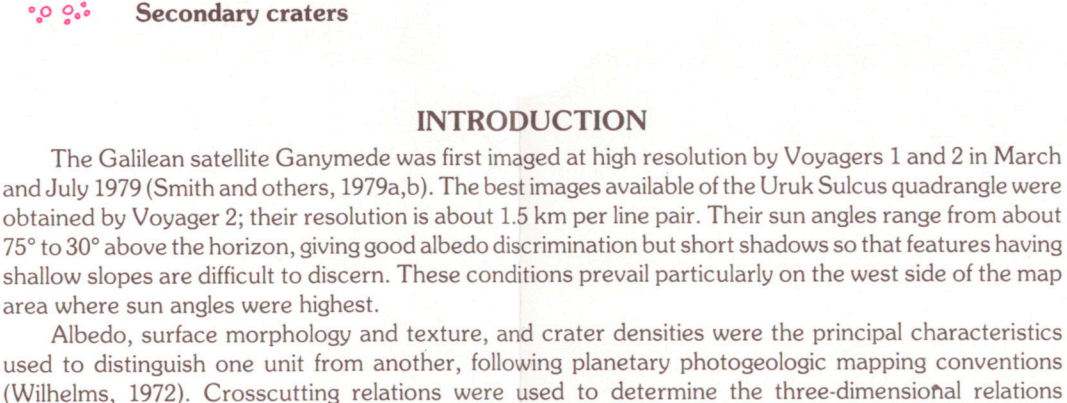
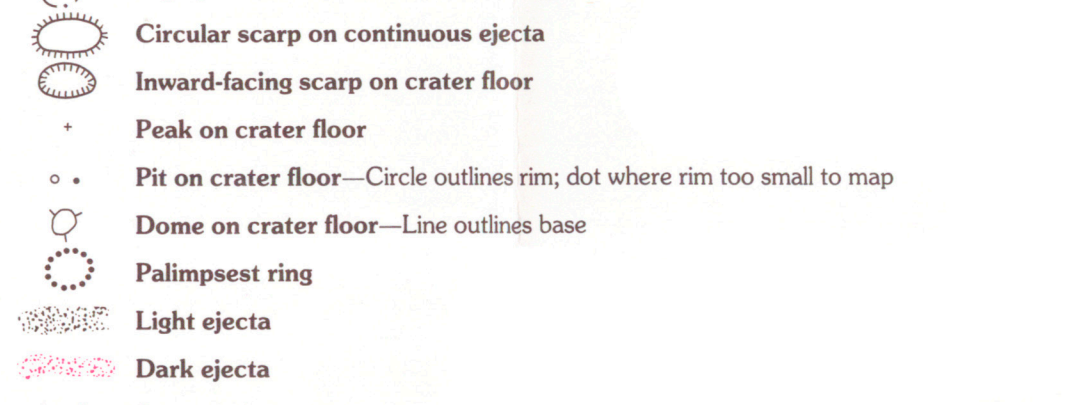
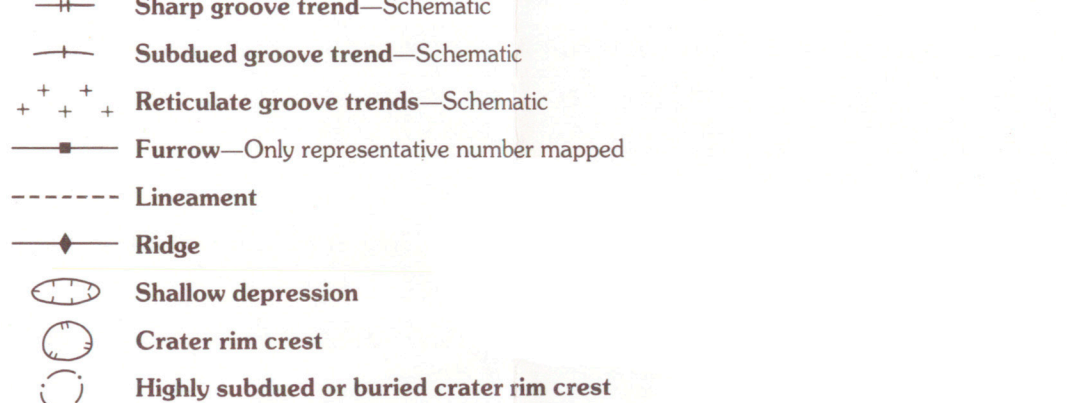
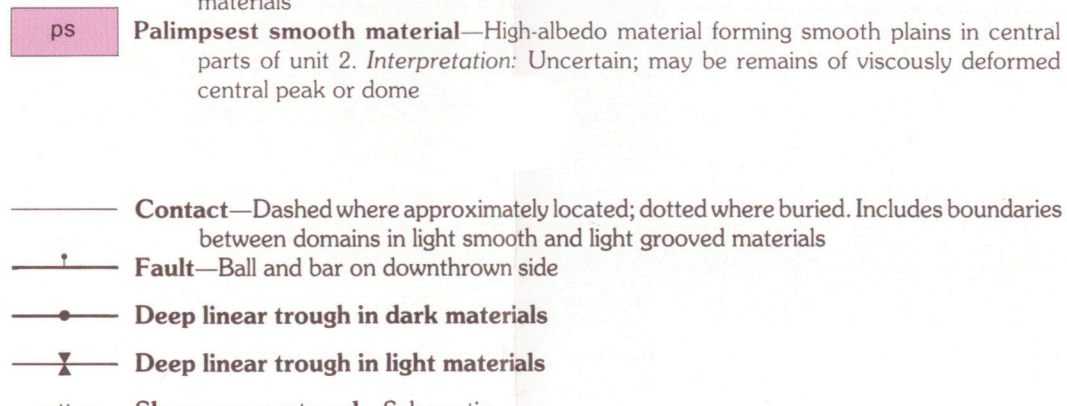
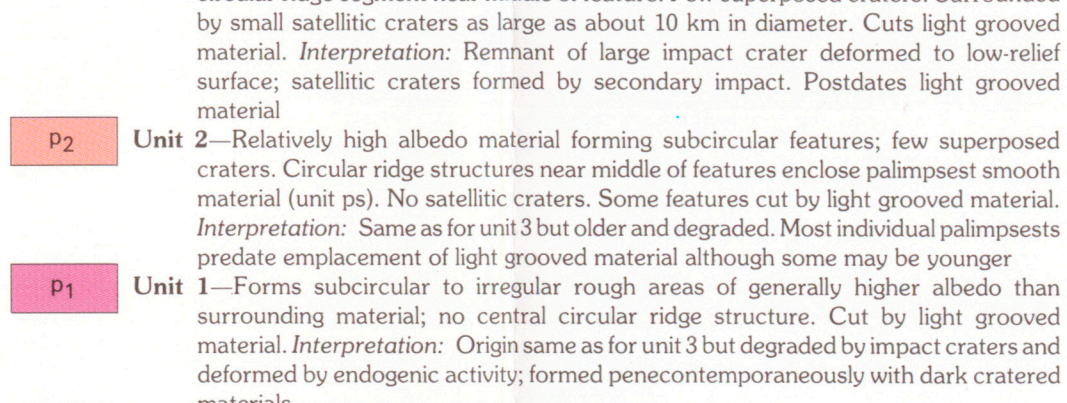
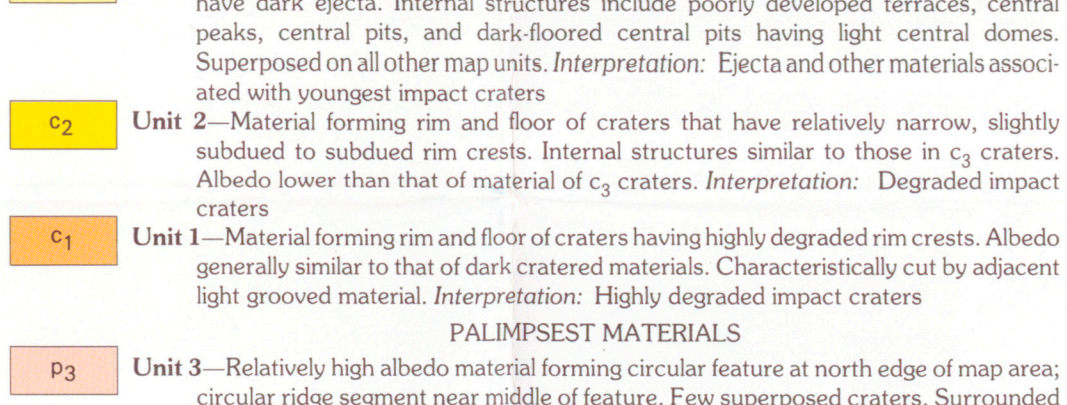
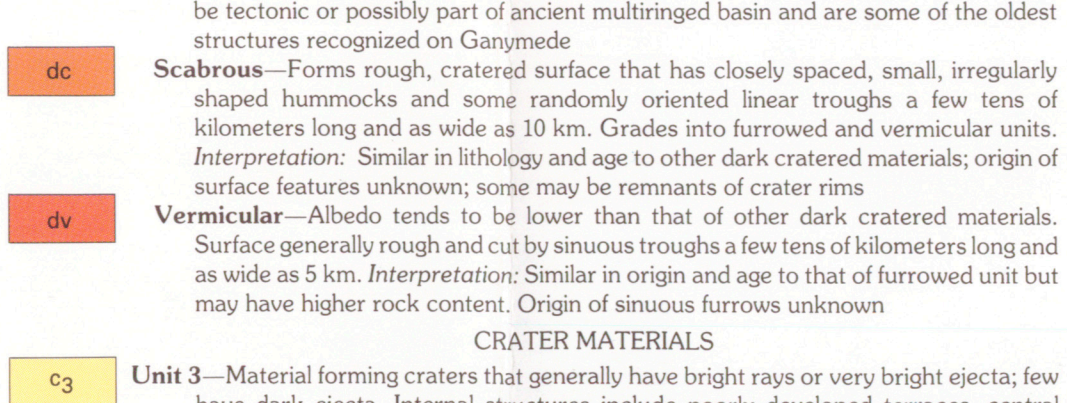
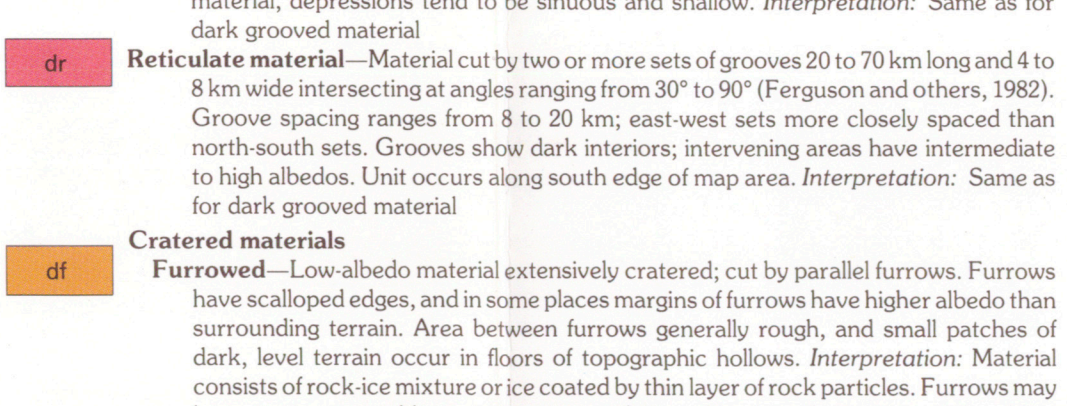
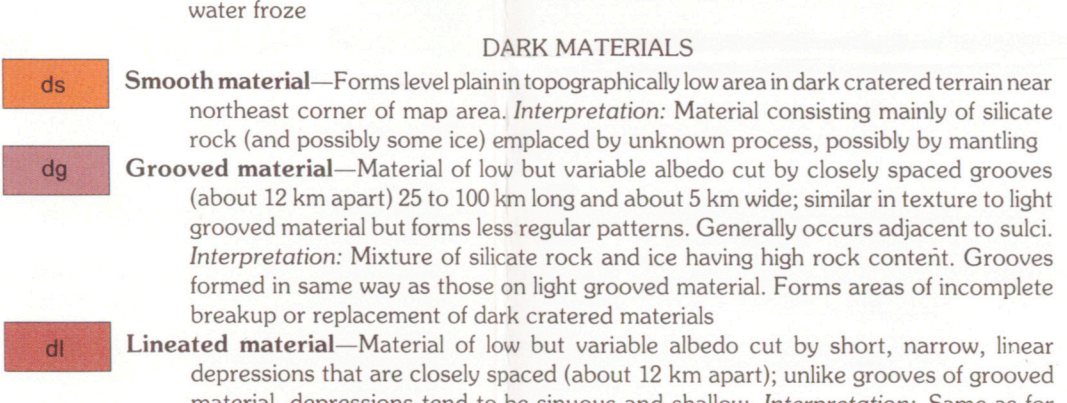
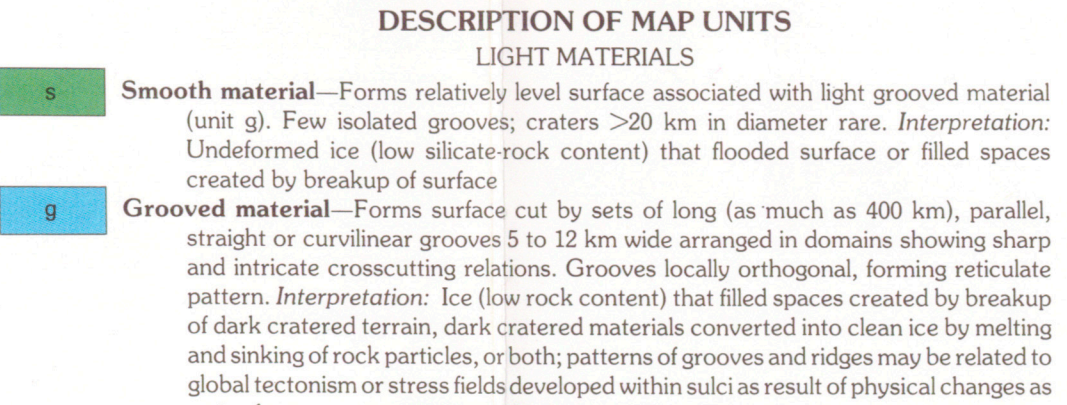
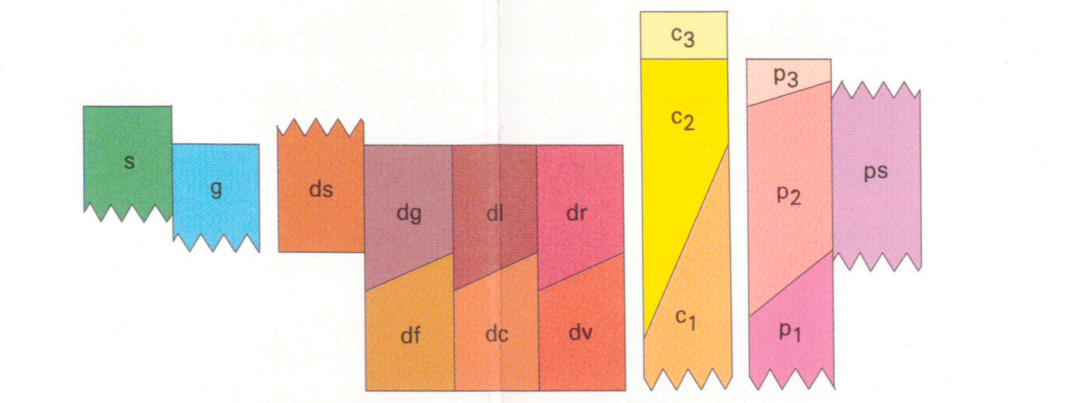
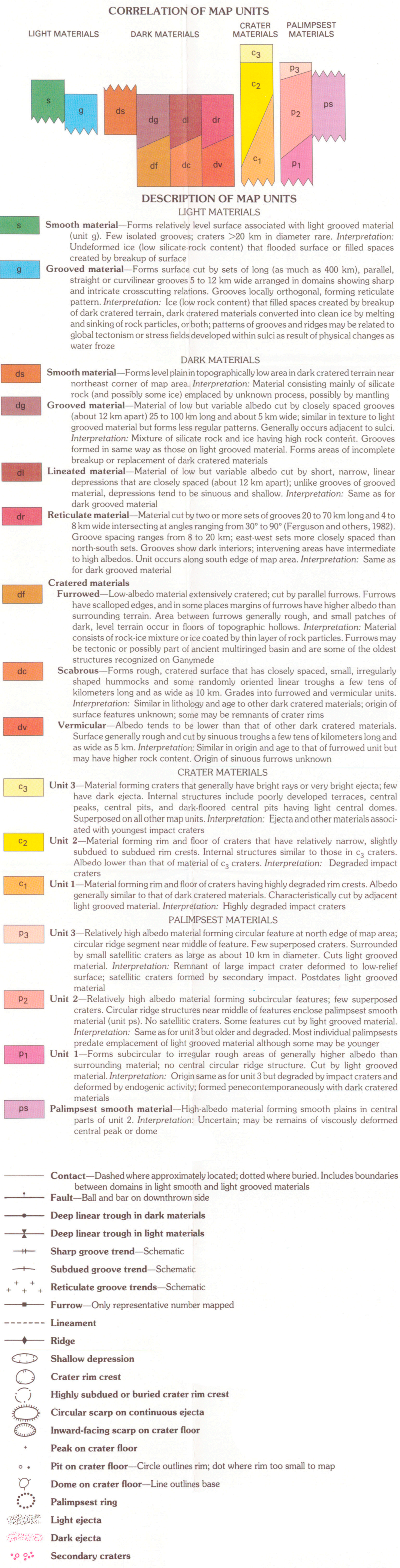
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GEOLOGIC MAP OF THE URUK SULCUS QUADRANGLE OF GANYMEDE

By
J.E. Guest, Remo Bianchi, and Ronald Greeley
1988



PHYSIOGRAPHIC SETTING
The surface of Ganymede may be divided into two distinct regions: older, dark cratered terrain and younger, light grooved terrain (Shoemaker and others, 1982). Slightly less than half of the surface of the satellite is composed of ancient cratered terrain (Shoemaker and others, 1982).
The Uruk Sulcus quadrangle lies along the south margin of Galileo Regio, a large area of ancient cratered terrain, part of which appears in the northwest corner of the map area. Galileo Regio is separated from Marius Regio, another region of ancient terrain to the southwest, by a swath of grooved terrain known as Uruk Sulcus. Marius Regio is in turn broken by bands of grooved terrain, including Tamat Sulcus, which cut across the southwestern part of the map area. Each of these major terrains is probably of roughly uniform lithology, but they may be divided into smaller units of stratigraphic or tectonic significance or both.
Superposed on all these units are impact craters and their associated deposits. These range in degree of preservation from crisp craters exhibiting bright or dark rays to shallow craters that have degraded rim crests and no discernible ejecta deposits. Large subcircular areas of relatively high albedo, some of which contain low positive relief features, may be remnants of large craters. These features have been termed palimpsests by Smith and others (1979a).

STRATIGRAPHY
DARK MATERIALS
The dark, cratered units form irregularly shaped areas ranging in size from several thousand kilometers across (for example, Galileo Regio) to smaller areas tens to hundreds of kilometers across. Their main characteristics are low albedo and relative abundance of craters. In many areas the dark materials are cut by furrows and ridges of different sizes and morphologies. These features and the patterns they form, however, vary from one area to another. No distinct boundaries exist between areas of different patterns.
In the southwestern part of Galileo Regio and the northwestern part of Marius Regio in the map area, the dark cratered material characterized by subparallel linear furrows is mapped as furrowed material (unit df). The edges of the furrows are scalloped and tend to be associated with regions of slightly higher albedo than the surrounding terrain, especially in Galileo Regio. Furrows tend to be more closely spaced in Marius Regio than in Galileo Regio.
The vernal material (unit dv) occurs in the southeast corner of the map area and is identified by the presence of sinuous troughs that are randomly oriented. A third unit, termed scarious (unit dc), has few distinctive characteristics apart from small irregular hummocks giving a rough appearance. The relative ages of dark cratered materials are difficult to determine, and it is likely that the characteristics of these units result as much from tectonism as from differences in lithology.
Craters in the dark terrain range in size from the resolution limit to about 100 km across and range in age from those that are contemporaneous with the dark units to those that postdate all materials in the map area. Some craters, especially larger ones, are considered palimpsests (Smith and others, 1979a), which more commonly occur in the furrowed facies of Marius Regio. In the furrowed material, all observed craters are superposed on the furrows. This observation implies that the craters postdate the furrows and confirms the view of Casaccia and Strom (1984) that the furrows are some of the oldest features on Ganymede. The oldest palimpsest material (unit p₁) is, however, cut by furrows in places.
Within the dark cratered materials (especially in the furrowed unit) are small areas of dark plains, one of which is large enough to be mapped as dark smooth material (unit ds).
Along the boundaries between the dark cratered materials and the light materials of the sulci, dark materials occur that have surface characteristics in common with those of the light materials. The dark grooved material (unit dg) has some patches of higher albedo and fewer superposed craters than are seen on the dark cratered materials; most craters are strongly degraded. In this unit the parallel grooves are similar to those in the light grooved terrain, but the general pattern is not as well developed, and there are no distinct domains of groove sets.
The dark lineated material (unit dl) associated with Tamat Sulcus, like the dark grooved material, probably represents the partial breakup of dark cratered materials by processes similar to those that formed the light grooved material. Some areas of the southeastern extension of Tamat Sulcus contain dark reticulate material (unit dr) originally defined by Ferguson and others (1982).

LIGHT MATERIALS
Light materials form two major northwest-trending sulci across the area. Their widths range from 100 km to more than 500 km. In addition, narrow zones of light material, some 10 km wide and as long as 80 km, cut the dark cratered materials. Most of the light material is grooved to varied degrees (unit g), and it is subdivided into domains of different groove orientations. The grooves in Uruk Sulcus tend to be oriented either parallel or perpendicular to the axis of the sulcus (Bianchi and others, 1984). Two domains in the southwestern part of the map area show a reticulate pattern of grooves similar to that of the dark reticulate material, but the grooves are more closely spaced. Most domains are bounded by a deep trough interpreted to be a graben; these troughs are not depicted on the map unless they cut across a domain.
Of lesser areal extent is light smooth material (unit s), which has an albedo similar to that of the light grooved material and which occurs as patches within it.

PALIMPSEST MATERIALS
These materials form subcircular areas 100 km to nearly 400 km across that are generally brighter than the surrounding terrain. Crosscutting relations indicate that palimpsests range in age from older to younger than light grooved material. Ancient palimpsest material (unit p₁) forms the least circular outcrops of all the palimpsest materials and occurs only within the dark cratered materials. The superposed impact-crater densities are similar to those of the dark cratered materials. Unit 2 of the palimpsest materials (unit p₂) occurs within the dark cratered terrain, and crosscutting relations suggest that most, if not all, of this material is older than the light grooved terrain. Many of these palimpsests contain areas of palimpsest smooth material (unit ps), which, in some cases, is surrounded by a circular ridge. The youngest palimpsest material (unit p₃) forms a circular feature surrounded by clusters of satellite craters; all are superposed on light grooved material as well as on dark material. This superposition and the apparent freshness of the features indicate its relative youth.

CRATER MATERIALS
Impact craters in the Uruk Sulcus quadrangle range in morphology from fresh, crisp craters that have well-defined ejecta and rays to features that have low, narrow, battered rims. However, the degree of degradation may not be a good indication of age on Ganymede: first, the initial crater shape may be influenced by the physical characteristics of the lithosphere and its thickness (Greeley and others, 1982), both of which may have varied in time and place; and, second, the rate of degradation may be controlled by subsequent impact and the state of the lithosphere (Bianchi and Pozio, 1985).
The most degraded crater material (unit c₁) is distorted and cut by light grooved material, although in a few places the craters postdate the light grooved material.
The most common type of crater material (unit c₂) formed during nearly the entire history of the map area and is found on almost all units. The least degraded crater material (unit c₃) postdates the light grooved and light smooth materials.
Some small craters that have light central domes are floored by dark materials. A few of the fresh craters appear to have produced low-albedo ejecta, which indicates the presence of dark rocky layers below the surface. Although most crater ejecta are featureless, some form a concentric, shallow, outward-facing scarp similar to that of pedestal craters on Mars (Horne and Greeley, 1982).

STRUCTURAL AND GEOLOGIC HISTORY
The interpretable geologic history within the Uruk Sulcus quadrangle begins with the period of formation of the dark cratered materials. These probably consist of a mixture of ice and silicate rocky material, giving a relatively dark appearance, and may represent the original planetary crust following accretion of the satellite. After (and possibly during) its formation, some areas of the surface were deformed to produce furrows (unit df), either by internal processes (Casaccia and Strom, 1984) or as a result of basin-forming impact events (Smith and others, 1979a; McKinnon and Melosh, 1980). Most of the preserved craters were formed after the furrows, which suggests either that the furrows were produced relatively quickly or that the impact rate was low during their time of formation. However, the most ancient palimpsest material in the area appears to have formed precontemporaneously with the furrows because it is cut by some of them. The furrows, therefore, probably are the oldest structural features in the map area.
Areas of dark cratered materials other than the furrowed material continued to be modified by internal processes, resulting in the vernal and scarious textures. This modification was accompanied and followed by the excavation of impact craters.
The next major event in the history of the map area was the breakup of the lithosphere, which consisted of the dark cratered materials. This breakup may have been caused by global expansion due to phase changes of ice in the interior (Squires, 1980; Parmentier and others, 1982) or by mantle convection causing global tectonic stresses (Bianchi and others, 1986). As the lithosphere broke up, water or a slush of water and ice welled up and froze at the surface, forming the light materials (Lucchitta, 1980). During freezing and afterward, tectonic stresses, together with stresses caused by volume changes during freezing, resulted in the patterns of grooves and grabens in the light materials. At the margins of the sulci, the dark cratered materials were probably modified as a result of local stresses and temperature changes to form the smooth, grooved, lineated, and reticulate units of the dark materials.

Probably because of lithospheric thickening, no other major tectonic events occurred later in the history of the area. Minor eruptions of liquid water may have formed some areas of light smooth material, and occasional impacts produced c₃ craters; one impact was large enough to produce a palimpsest (unit p₃).

REFERENCES CITED
Bianchi, Remo, Casaccia, Ruggero, Lanciano, Pasquale, Pozio, Stefania, and Strom, R.G., 1986, Tectonic framework of grooved terrain on Ganymede: Icarus, v. 67, p. 227-250.
Bianchi, Remo, Casaccia, Ruggero, and Pozio, Stefania, 1984, Tectonics of the grooved terrain on Ganymede, in Abstracts of Papers Submitted to the Fifteenth Lunar and Planetary Science Conference, Houston, March 1984, p. 54-55.
Bianchi, Remo, and Pozio, Stefania, 1985, Morphometrical analysis of craters with domed central pit on Ganymede: Annales Geophysicae, v. 3, p. 129-134.
Casaccia, Ruggero, and Strom, R.G., 1984, Geologic evolution of Galileo Regio, Ganymede, in Lunar and Planetary Science Conference, 14th, Houston, 1983, Proceedings, part 2, Journal of Geophysical Research, v. 89, Supplement, p. B419-428.
Ferguson, H.M., Lucchitta, B.K., Squires, S.W., and Wilhelm, D.E., 1982, Geologic map of Ganymede, in Morrison, David, ed., Satellites of Jupiter: Tucson, University of Arizona Press, p. 938-959.
Greeley, Ronald, Fink, J.H., Gault, D.E., and Guest, J.E., 1982, Experimental simulation of impact cratering on icy satellites, in Morrison, David, ed., Satellites of Jupiter: Tucson, University of Arizona Press, p. 340-378.
Horne, V.M., and Greeley, Ronald, 1982, Pedestal craters on Ganymede: Icarus, v. 51, p. 549-562.
Lucchitta, B.K., 1980, Grooved terrain on Ganymede: Icarus, v. 44, p. 481-501.
McKinnon, W.B., and Melosh, M.J., 1980, Evolution of planetary lithospheres: Evidence from multiringed structures on Ganymede and Callisto: Icarus, v. 44, p. 454-471.
Morrison, David, 1982, Introduction to the satellites of Jupiter, in Morrison, David, ed., Satellites of Jupiter: Tucson, University of Arizona Press, p. 3-43.
Parmentier, E.M., Squires, S.W., Head, J.W., and Allison, M.L., 1982, The tectonics of Ganymede: Nature, v. 295, p. 290-293.
Shoemaker, E.M., Lucchitta, B.K., Plescia, J.B., Squires, S.W., and Wilhelm, D.E., 1982, The geology of Ganymede, in Morrison, David, ed., Satellites of Jupiter: Tucson, University of Arizona Press, p. 435-520.
Smith, B.A., and the Voyager Team, 1979a, The Galilean satellites and Jupiter: Voyager 2 imaging science results: Science, v. 206, p. 927-950.
1979b, The Jupiter system through the eyes of Voyager 1: Science, v. 204, p. 951-972.
Squires, S.W., 1980, Volume changes in Ganymede and Callisto and the origin of grooved terrain: Geophysical Research Letters, v. 7, p. 593-596.
Wilhelms, D.E., 1972, Geological mapping of the second planet, in U.S. Geological Survey Interagency Report: Astrogeology, v. 55, 39 p.