GEOLOGIC MAP OF THE URUK SULCUS QUADRANGLE (Jg-8) OF GANYMEDE

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DESCRIPTION OF MAP UNITS

LIGHT MATERIALS

s **Smooth material**—Forms relatively level surface associated with light grooved material (unit g). Few isolated grooves; craters >20 km in diameter rare. *Interpretation:* Undeformed ice (low silicate-rock content) that flooded surface or filled spaces created by breakup of surface

g **Grooved material**—Forms surface cut by sets of long (as much as 400 km), parallel, straight or curvilinear grooves 5 to 12 km wide arranged in domains showing sharp and intricate crosscutting relations. Grooves locally orthogonal, forming reticulate pattern. *Interpretation:* Ice (low rock content) that filled spaces created by breakup of dark cratered terrain, dark cratered materials converted into clean ice by melting and sinking of rock particles, or both; patterns of grooves and ridges may be related to global tectonism or stress fields developed within sulci as result of physical changes as water froze

DARK MATERIALS

ds **Smooth material**—Forms level plain in topographically low area in dark cratered terrain near northeast corner of map area *Interpretation:* Material consisting mainly of silicate rock (and possibly some ice) emplaced by unknown process, possibly by mantling

dg **Grooved material**—Material of low but variable albedo cut by closely spaced grooves (about 12 km apart) 25 to 100 km long and about 5 km wide; similar in texture to light grooved material but forms less regular patterns. Generally occurs adjacent to sulci. *Interpretation:* Mixture of silicate rock and ice having high rock content. Grooves formed in same way as those on light grooved material. Forms areas of incomplete breakup or replacement of dark cratered materials

dl **Lineated material**—Material of low but variable albedo cut by short, narrow, linear depressions that are closely spaced (about 12 km apart); unlike grooves of grooved material, depressions tend to be sinuous and shallow. *Interpretation:* Same as for dark grooved material

dr **Reticulate material**—Material cut by two or more sets of grooves 20 to 70 km long and 4 to 8 km wide intersecting at angles ranging from 30° to 90° (Ferguson and others, 1982). Groove spacing ranges from 8 to 20 km; east-west sets more closely spaced than north-south sets. Grooves show dark interiors; intervening areas have intermediate to high albedos. Unit occurs along south edge of map area. *Interpretation:* Same as for dark grooved material

Cratered materials

df **Furrowed**—Low-albedo material extensively cratered; cut by parallel furrows. Furrows have scalloped edges, and in some places margins of furrows have higher albedo than surrounding terrain. Area between furrows generally rough, and small patches of dark, level terrain occur in floors of topographic hollows. *Interpretation:* Material consists of rock-ice mixture or ice coated by thin layer of rock particles. Furrows may be tectonic or possibly part of ancient multiringed basin and are some of the oldest structures recognized on Ganymede dc **Scabrous—**Forms rough, cratered surface that has closely spaced, small, irregularly shaped hummocks and some randomly oriented linear troughs a few tens of kilometers long and as wide as 10 km. Grades into furrowed and vermicular units. *Interpretation:* Similar in lithology and age to other dark cratered materials; origin of surface features unknown; some may be remnants of crater rims

dv **Vermicular**—Albedo tends to be lower than that of other dark cratered materials. Surface generally rough and cut by sinuous troughs a few tens of kilometers long and as wide as 5 km. *Interpretation:* Similar in origin and age to that of furrowed unit but may have higher rock content. Origin of sinuous furrows unknown

CRATER MATERIALS

c3 **Unit 3**—Material forming craters that generally have bright rays or very bright ejecta; few have dark ejecta. Internal structures include poorly developed terraces, central peaks, central pits, and dark-floored central pits having light central domes. Superposed on all other map units. *Interpretation:* Ejecta and other materials associated with youngest impact craters

c2 **Unit 2**—Material forming rim and floor of craters that have relatively narrow, slightly subdued to subdued rim crests. Internal structures similar to those in c_3 craters. Albedo lower than that of material of c_3 craters. *Interpretation:* Degraded impact craters

c1 **Unit 1—**Material forming rim and floor of craters having highly degraded rim crests. Albedo generally similar to that of dark cratered materials. Characteristically cut by adjacent light grooved material. *Interpretation:* Highly degraded impact craters

PALIMPSEST MATERIALS

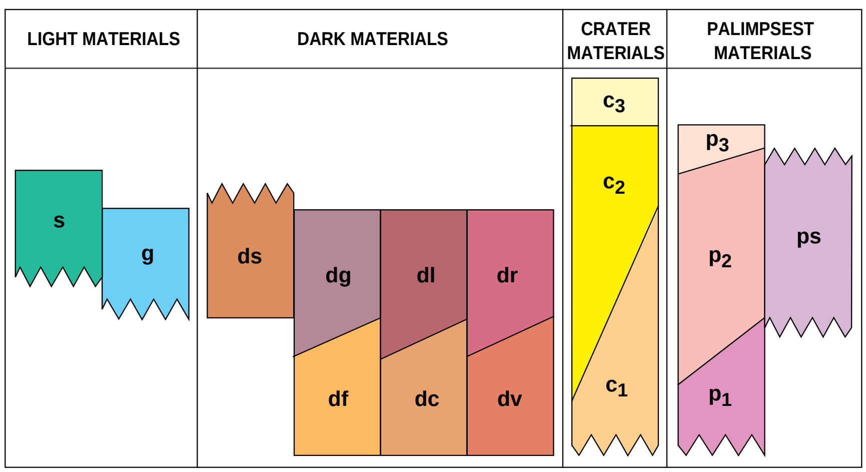
p3 **Unit 3**—Relatively high albedo material forming circular feature at north edge of map area; circular ridge segment near middle of feature. Few superposed craters. Surrounded by small satellitic craters as large as about 10 km in diameter. Cuts light grooved material. *Interpretation:* Remnant of large impact crater deformed to low-relief surface; satellitic craters formed by secondary impact. Postdates light grooved material

p2 **Unit 2**—Relatively high albedo material forming subcircular features; few superposed craters. Circular ridge structures near middle of features enclose palimpsest smooth material (unit ps). No satellitic craters. Some features cut by light grooved material. *Interpretation:* Same as for unit 3 but older and degraded. Most individual palimpsests predate emplacement of light grooved material although some may be younger

p1 **Unit 1**—Forms subcircular to irregular rough areas of generally higher albedo than surrounding material; no central circular ridge structure. Cut by light grooved material. *Interpretation:* Origin same as for unit 3 but degraded by impact craters and deformed by endogenic activity; formed penecontemporaneously with dark cratered materials

ps **Palimpsest smooth material—**High-albedo material forming smooth plains in central parts of unit 2. *Interpretation:* Uncertain; may be remains of viscously deformed central peak or dome

CORRELATION OF MAP UNITS



Contact—Dashed where approximately located; dotted where buried. Includes boundaries between domains in light smooth and light grooved materials

Fault—Ball and bar on downthrown side

Deep linear trough in dark materials

Deep linear trough in light materials

Sharp groove trend—Schematic

Subdued groove trend—Schematic

Reticulate groove trends—Schematic

Furrow—Only representative number mapped

Lineament

Ridge

Shallow depression

Crater rim crest

Highly subdued or buried crater rim crest

Circular scarp on continuous ejecta

Inward-facing scarp on crater floor

Peak on crater floor

Pit on crater floor—Circle outlines rim; dot where rim too small to map

Dome on crater floor—Line outlines base

Palimpsest ring

Light ejecta

Dark ejecta

Secondary craters

INTRODUCTION

The Galilean satellite Ganymede was first imaged at high resolution by Voyagers 1 and 2 in March and July 1979 (Smith and others, 1979a, b). The best images available of the Uruk Sulcus quadrangle were obtained by Voyager 2; their resolution is about 1.5 km per line pair. Their sun angles range from about 75° to 30° above the horizon, giving good albedo discrimination but short shadows so that features having shallow slopes are difficult to discern. These conditions prevail particularly on the west side of the map area where sun angles were highest.

Albedo, surface morphology and texture, and crater densities were the principal characteristics used to distinguish one unit from another, following planetary photogeologic mapping conventions (Wilhelms, 1972). Crosscutting relations were used to determine the three-dimensional relations between units. However, unlike the terrestrial planets, for which the techniques for planetary geologic mapping were developed, Ganymede has landforms that, apart from impact craters, are largely structural features. Although every effort was made to identify individual material units, the map has as much in common with tectonic maps as with geologic maps on which units are distinguished in terms of lithology and age. Thus, on this map some units of the same apparent lithology and age are distinguished from one another by different surface features.

On the basis of its density (1.93 g cm^{-3}) and spectroscopic studies of its surface, Ganymede is considered to be composed dominantly of water ice (Morrison, 1982). Differences in albedo between units may be related to the amount and composition of rocky material mixed with ice. Because the physical characteristics of ice are different from those of silicate rocks, geologic interpretation of Ganymede relies much less on terrestrial analogs than do interpretations of the terrestrial planets.

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 northeast 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 Tiamat 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 vermicular 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 scabrous (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 Casacchia and Strom (1984) that the furrows are some of the oldest features on Ganymede. The oldest palimpsest material (unit p_1) 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 Tiamat 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 Tiamat 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 p_l) 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 p_2) 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 p_3)

forms a circular feature surrounded by clusters of satellitic craters; all are superposed on light grooved material as well as on dark material. This superposition and the apparent freshness of the feature 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 c_1) 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 c_2) formed during nearly the entire history of the map area and is found on almost all units. The least degraded crater material (unit c_3) 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 (Horner 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 (Casacchia 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 penecontemporaneously 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 vermicular and scabrous 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 (Squyres, 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 matelials.

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 c_3 craters; one impact was large enough to produce a palimpsest (unit p_3).

REFERENCES CITED

Bianchi, Remo, Casacchia, Ruggero, Lanciano, Pasquale, Pozio, Stefania, and Strom, R.G., 1986, Tectonic framework of grooved terrain on Ganymede: Icarus, v. 67, p. 237–250.

Bianchi, Remo, Casacchia, 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.

Casacchia, 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., Squyres, S.W., and Wilhelms, D.E., 1982, Geologic map of Ganymede, *in* Morrison, David, ed., Satellites of Jupiter: Tucson, University of Arizona Press, p. 938–939.

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.

Horner, 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., Squyres, S.W., Head, J.W., and Allison, M.L., 1982, The tectonics of Ganymede: Nature, v. 295, p. 290–293.

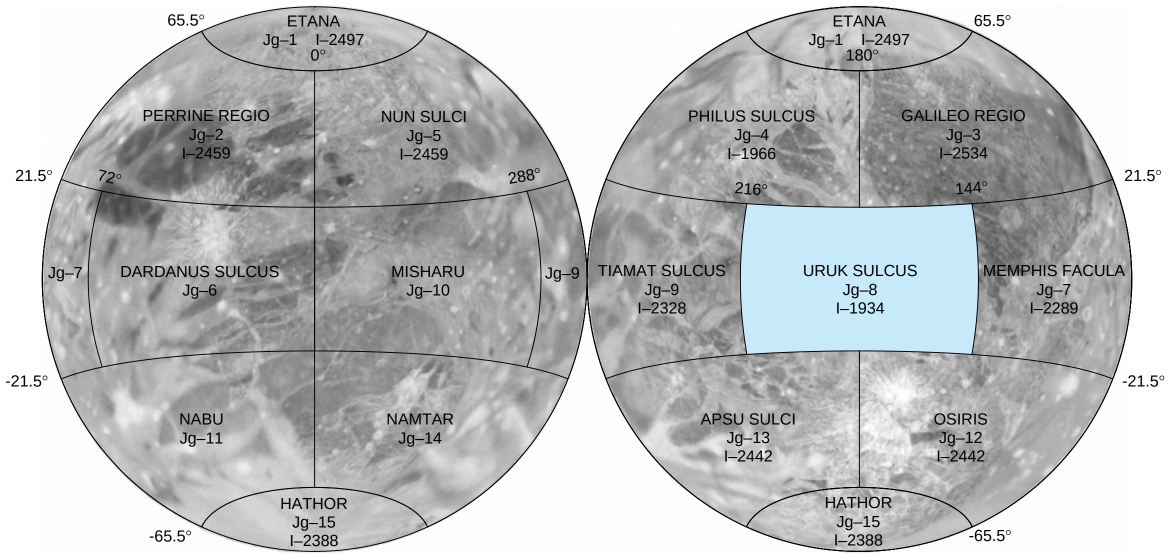
Shoemaker, E.M., Lucchitta, B.K., Plescia, J.B., Squyres, S.W., and Wilhelms, D.E., 1982, The geology of Ganymede, *in* Morrison, David, ed., Satellites of Jupiter: Tucson, University of Arizona Press, p. 435–520.

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.

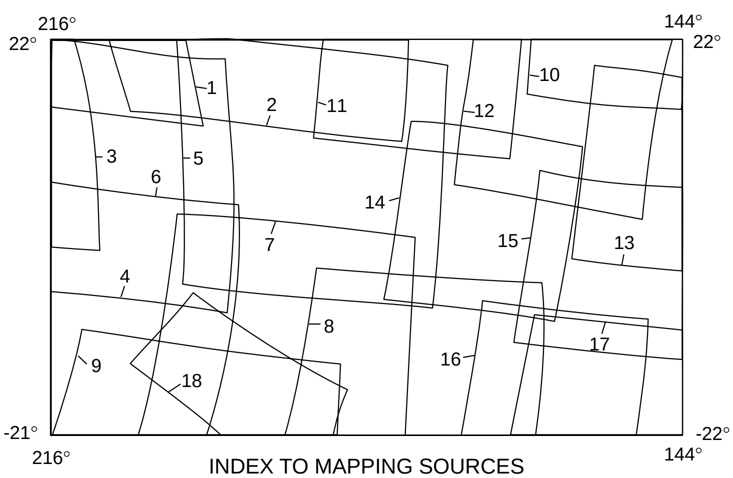
Squyres, S.W., 1980, Volume changes in Ganymede and Callisto and the origin of grooved terrain: Geophysical Research Letters, v. 7, p. 593–596.

Wilhelms, D.E., 1972, Geological mapping of the second planet, *in* U.S. Geological Survey Interagency Report: Astrogeology, v. 55, 39 p.



QUADRANGLE LOCATION

Number preceded by I refers to published geologic map



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 enhancements of these pictures are available from National Space Science Data Center, Code 601, Goddard Space Flight Center, Greenbelt, MD 20771.

Primary Source

VOYAGER 2

Index No.	Picture No.
1	0366J2-001
2	0370J2-001
3	0374J2-001
4	0378J2-001
5	0382J2-001
6	0389J2-001
7	0392J2-001
8	0395J2-001
9	0404J2-001
10	0452J2-001
11	0458J2-001
13	0464J2-001
14	0470J2-001
15	0473J2-001
16	0482J2-001
17	0485J2-001
18	0622J2-001

Supplemental Source

VOYAGER 1

Picture No.
0268J1-004
1207J1-004
0015J1-003
0539J1-003

VOYAGER 2

Picture No.	Picture No.
1756J2-004	0384J2-001
0809J2-003	0386J2-001
0528J2-002	0398J2-001
0092J2-001	0401J2-001
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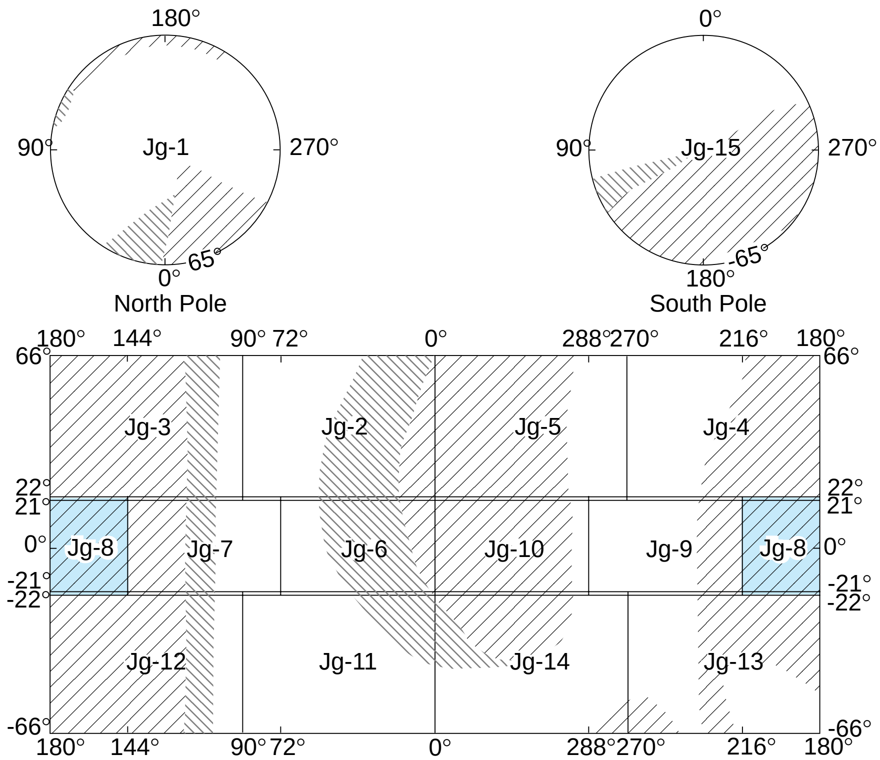

Approximate resolution of available Voyager images expressed
as kilometers per picture element (pxl)