# GEOLOGIC MAP OF THE EAST SIDE OF THE MOON

By
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1977

Prepared for the
National Aeronautics and Space Administration
by
U.S. Department of the Interior, U.S. Geological Survey

(Published in hardcopy as USGS Miscellaneous Investigations Series Map I–948, as part of the Geologic Atlas of the Moon, 1:5,000,000 Geologic Series. Hardcopy is available for sale from U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225)

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# DESCRIPTION OF MAP UNITS

## CRATER MATERIALS
(craters 20-km rim crest diameter or larger)

| | |
|---|---|
| Cc | MATERIAL OF RAYED CRATERS |
| Ec | MATERIAL OF FRESH NONRAYED CIRCULAR CRATERS |
| $Ic_2$ | MATERIAL OF MODERATELY FRESH CIRCULAR CRATERS—Older than younger mare material ($Im_2$) and younger than or about the same age as the Orientale basin (outside map area) |
| $Ic_1$ | MATERIAL OF MODERATELY SUBDUED CIRCULAR CRATERS—Older than the Orientale basin and younger than the Imbrium basin (outside map area) |
| Nc | MATERIAL OF SUBDUED CIRCULAR CRATERS—Older than the Imbrium basin and as young as or younger than the Janssen Formation |
| pNc | MATERIAL OF HIGHLY SUBDUED, MOSTLY NARROW-RIMMED CIRCULAR CRATERS—Older than the Janssen Formation |
| Isc | MATERIAL OF SECONDARY CRATER CLUSTERS AND CHAINS |
| Irc | MATERIAL OF RINGED CRATERS—Circular; one or more inner concentric rings; shallow floors; rims narrow and smooth |
| Icc | MATERIAL OF MODERATELY FRESH CRATER CHAINS, CLUSTERS, AND IRREGULAR CRATERS |
| Ifc | MATERIAL OF FURROWED CRATER FLOORS—Domed or nearly flat, transected by cracks |
| Ncc | MATERIAL OF SUBDUED CRATER CLUSTERS, CHAINS, AND IRREGULAR CRATERS—Includes long, linear, valleylike chains and irregular depressions |
| pNcc | MATERIAL OF HIGHLY SUBDUED CRATER CHAINS, CLUSTERS, AND IRREGULAR CRATERS |

## BASIN MATERIALS

| | |
|---|---|
| Nb | BASIN MATERIAL, UNDIVIDED—Moderately rough surface on elevated craterlike rings of small basins younger than Nectaris |
| Nbl | LINEATED MATERIAL AROUND BASINS—Younger than the Janssen Formation |
| Nj | JANSSEN FORMATION (basal Nectarian)—lineated material around Nectaris basin; more highly cratered than Imbrium basin ejecta blanket |
| pNbm | MATERIAL OF BASIN MASSIFS—Mountainous, high-standing, smooth-sided blocks mostly with high albedo; associated with basins older than Nectaris |
| pNbr | MATERIAL OF RUGGED BASIN TERRAIN—Rugged peaks and ridges smaller than the massifs, mostly in and peripheral to basins older than Nectaris. Also includes two short smooth |

| | |
|---|---|
| | arcs: northwest part of outer Al-Khwarizmi-King basin ring, and part of Tsiolkovsky-Stark basin ring near crater Stark |
| NpNbm | MATERIAL OF BASIN MASSIFS (Nectarian and pre-Nectarian) Similar to unit pNbm but associated with basins of Nectarian age |
| NpNbr | MATERIAL OF RUGGED BASIN TERRAIN (Nectarian and pre-Nectarian)—Similar to unit pNbr but associated with basins of Nectarian age |

## OTHER TERRA MATERIALS

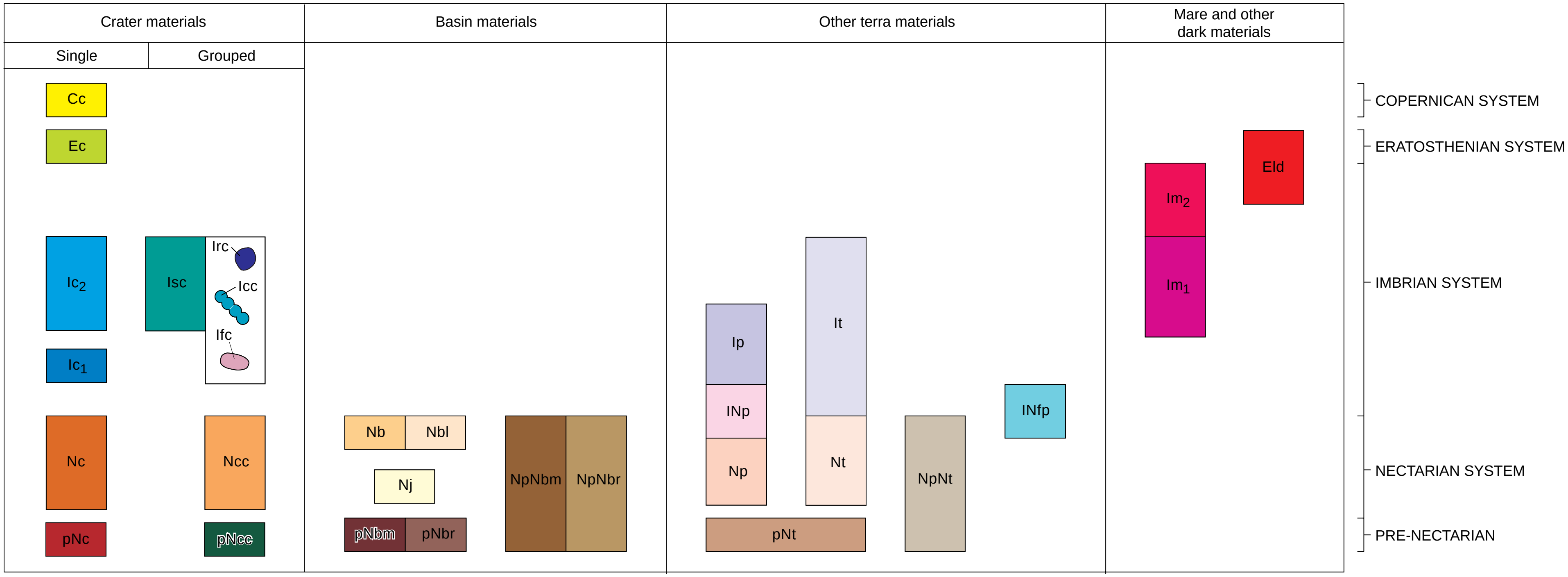
| | |
|---|---|
| Ip | LIGHT-COLORED PLAINS MATERIAL—Level, smooth surface; density and morphology of superposed craters indicate middle Imbrian age |
| INp | LIGHT-COLORED PLAINS MATERIAL (Imbrian or Nectarian)—Level or somewhat undulatory surface; superposed craters indicate early Imbrian or late Nectarian age; plains between Petavius and Humboldt could be middle Imbrian |
| Np | LIGHT-COLORED PLAINS MATERIAL—Similar to unit INp but superposed craters tentatively indicate Nectarian age |
| It | TERRA MANTLING MATERIAL—Undulatory, moderately smooth surface; superposed craters indicate Imbrian age |
| Nt | TERRA MANTLING MATERIAL—Similar to unit It but superposed craters indicate Nectarian age |
| pNt | MATERIAL OF UNMANTLED TERRA—Moderately rugged; individual relief elements are mostly parts of craters |
| NpNt | MATERIAL OF PARTLY MANTLED TERRA (Nectarian and pre-Nectarian)—Smooth or moderately rough surface, rolling to moderately rugged overall relief; age of superposed and buried craters laterally diverse |
| INfp | FURROWED AND PITTED MATERIAL (Imbrian or Nectarian)—Closely spaced irregular sinuous furrows and (or) circular, elongate, or irregular pits; kilometers in size; furrows dominant in large patches north of Mare Marginis and Mare Fecunditatis, pits elsewhere. Locally superposed on Nectarian-age craters and overlain by lower Imbrian craters; perhaps variable in age |

## MARE AND OTHER DARK MATERIALS

| | |
|---|---|
| $Im_2$ | YOUNGER MARE MATERIAL—Similar in dark color and crater density to typical near-side mare material of late Imbrian age; perhaps varable in age |
| $Im_1$ | OLDER MARE MATERIAL—Superposed craters indicate middle Imbrian age. Lighter color than unit $Im_2$ and most near-side unrayed mare, similar to near-side rayed mare as between Langrenus and west map border, and darker than light-colored plains material (units Ip, INp, Np) |
| EId | DARK MATERIAL (Eratosthenian or Imbrian)—Several types of material with albedo of mare or darker, including deposits with intrinsic fresh-appearing textures (Mare Smythii, |

especially lat 6° S., long 84° E.), cones (Cleomedes), hummocky deposits and sharp, elongate furrows (between Scaliger and Titius, lat 26 S., long 102° E.), mantles without apparent relief of their own (Mare Smythii, Petavius, Humboldt, Tsiolkovsky), and dark halos around elongate furrows (Messala). Same age or younger than younger mare material (Im2)

# CORRELATION OF MAP UNITS



| | |
|---|---|
| — | Contact—Queried where location very uncertain (in northeast quadrant) |
| — | Crest of basin ring structure (generalized)—Dashed where inferred from mare ridges, relatively low terra features, or widely separated terra hills* |
| — - - — | Buried crater rim crest |
| ░ | Bright sinuous markings |

* Note added in proof: Mountains in the southeast corner of the map area (mapped as units pNbm and pNbr and as province bo) may be parts of a ring of a very old basin not identified during the preparation of this map. This is the South Pole—Aitken basin, about 2200 km in diameter, the largest lunar impact basin) so far discovered (Howard and others, 1974; Stuart-AIexander, 1977).

## GENERAL FEATURES

### MARIA AND MULTI-RING CIRCULAR BASINS

The map area is centered on the east limb of the moon as seen from Earth and includes 40° of longitude of the Earth-facing hemisphere and 50° of the far side. The geology of the whole region is controlled by the large features of impact origin known as multi-ring circular basins (Hartmann and Kuiper, 1962). Two basic types of terrain are present, maria and terrae. Basin and crater materials compose most of the terrae. The maria, of volcanic origin, are concentrated in the basins and in their peripheral troughs.

The maria are more extensive on the near side and the limb than on the far side (geologic map and fig. 1). On the near side (western part of the map area) they are concentrated in and around the high-rimmed Crisium basin, in the subdued Fecunditatis basin, and in peripheral troughs of the Serenitatis and Humboldtianum basins (northwest corner of map area). Mare materials of another near-side basin, Nectaris, lie entirely outside the map area, but the basin materials strongly affect the area. On the limb (central meridian of the map) the maria are in the weakly expressed Marginis basin, the subdued Smythii basin, and the large but shallow Australe basin (south edge of map area).

The Moscoviense basin contains mare just east of the map area, and other far-side mare patches occur in craters that are in turn superposed on basins. Conspicuous patches are in Tsiolkovsky, located near the center of an ancient, incomplete basin (Baldwin, 1969), and in Lomonosov, which lies just inside the projected edge of an old basin that has much light-plains fill. These basins are here named Tsiolkovsky-Stark and Lomonosov-Fleming after craters superposed on them. A conspicuous far-side patch of mare material that may not be related to either a basin or a crater is centered at lat 27° S., long 103° E.

Three far-side basins that contain no mare material have been identified. Mendeleev and Milne are small, craterlike, relatively young basins. Al-Khwarizmi-King, named after craters superposed on the outer of two mapped rings, is a larger, much older feature (El-Baz, 1973). Other ancient basins are probably present, and the entire map area has probably been reworked repeatedly by basin and crater formation (Baldwin, 1969; Howard and others, 1974).*

### GEOLOGIC PROVINCES

Geologic provinces are areas in which a geologic unit or groups of units related in age and origin are concentrated (McCauley and Wilhelms, 1971) In the map area (fig. 1) the maria are grouped into two provinces, young and old. At least three of six terra provinces consist mostly of basin materials. The youngest basins are surrounded by blankets of radially lineated ejecta and clusters of secondary impact

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* Note added in proof: Mountains in the southeast corner of the map area (mapped as units pNbm and pNbr and as province bo) may be parts of a ring of a very old basin not identified during the preparation of this map. This is the South Pole—Aitken basin, about 2200 km in diameter, the largest lunar impact basin) so far discovered (Howard and others, 1974; Stuart-AIexander, 1977).

craters (province by). The two largest occurrences fan out from the Humboldtianum basin, centered north of the map area, and the Nectaris basin, west of the southwest corner; smaller blankets surround Mendeleev, Milne, and Moscoviense. The lineated blankets and the secondary clusters are diagnostic of the impact origin of the source basins. A second province (bo), topographically more rugged than the first, forms the multiple rings and some peripheral terrain of several old basins.* Extensive tracts of terra that appear mantled occur near the young and old basins and form a third province (tm) . Although the distinctive lineated textures have not been observed in this mantle, its association with basins suggests that it is composed mostly of degraded basin ejecta.

Other terrain, mostly on the far side, consists of densely packed craters (province tc). This province contains little mantle or other basin material except the ancient, subdued rings of the Al-Khwarizmi-King, Tsiolkovsky-stark, and Lomonosov-Fleming basins, and a few additional short arcs of rings. Thus the province owes its preservation to lack of significant modification by young basins and is generally the most primitive province.

The two provinces of light plains, young and old, may or may not be related to basins. As discussed in the section on stratigraphy, they could be either ejecta from distant basins or volcanic rock. Notable concentrations occur in the Lomonosov-Fleming basin, near the Smythii basin, southeast of Langrenus, and in the northwest corner of the map area.

## GEOPHYSICS AND GEOCHEMISTRY

Laser altimeters carried by orbiting Apollo spacecraft measured absolute elevations and delineated many topographic features of the area (Kaula and others, 1972, 1973). Two representative profiles (*A-A'*, fig. 2; *B-B'*, fig 3) show that the near side in the map area averages about 3 km lower in elevation than the far side. The near-side terrain traversed by the profiles is composed mostly of basin-related terra provinces and maria; the higher far-side terrain consists of the cratered terra province overlain by one younger, plains-filled basin (Mendeleev). Small peaks and troughs in the profiles belong to crater rims and interiors.

From this and additional data, Kaula, Schubert, Lingenfelter Sjogren, and Wollenhaupt (1973) have determined a 2– to 3– km offset toward the Earth of the center of mass of the Moon from its center of figure. They ascribe this to a variable thickness of a low-density terra crust, thinner on the near side than on the far side. They believe that the maria are concentrated on the near side because the mare basalts could more easily penetrate the thinner crust. Similarly, local thinning of crust through excavation by basins, and particularly by craters superposed on basins, may explain the observed distribution of maria on the far side.

X-ray fluorescence and gamma-ray spectrometers were carried in orbit on Apollo missions 15 and 16 to extend geochemical findings from the small spots sampled or analyzed by Surveyor, Apollo, and Luna missions to larger areas of the Moon. The X-ray results, reported as concentration ratios of aluminum or magnesium to silicon, are particularly significant in the map area. Comparisons can be drawn between these ratios and those obtained from analyses of returned rock and soil (Adler and others, 1972, 1973). Concentration ratios typical of mare and terra rocks are observed. Ratios of Al to Si (fig. 4) and Mg to Si (fig. 5) are, in general, inversely related. Extreme values of the ratios are obtained over relatively uninterrupted geologic units—low Al:Si and high Mg:Si over maria and the converse over highlands. This inverse relation holds over Fecunditatis, Crisium, and Smythii with two exceptions. First, Smythii has a higher Al:Si ratio than the other two maria (fig 4); this may be a result of mixture of small terra patches of the mantled terra province with mare patches. Second, the Mg:Si ratio characteristic of Fecunditatis extends farther east than the Al:Si ratio (fig. 5); this extension is over an area of Langrenus ejecta that probably contains fragments of mare rock. The mare-free cratered terra province has the two lowest Mg:Si ratios and the two highest Al:Si ratios; the latter also extend west of this province. Departures from exact inverse correlation may result from instrumental factors particularly in concentration ratios of Mg to Si.

Intermediate values of the two element ratios may result from mixtures of mare and terra end members caused either by lunar processes or by limited instrumental resolution. Zones of intermediate values occur near the large maria or correlate with regions in the central and western parts of the map area where small patches of mare and terra are intermixed. Impact cratering has probably mixed mare and terra materials in the regolith of such zones Also, the instruments integrate spectra over about 60 km$^2$ and combine mare and terra spectra that probably would appear unmixed if measured with finer resolution. An alternative possi- bility for intermediate values, which remains to be tested by additional data reduction and orbital missions, is the presence of geochemical provinces in the terra that do not correspond to mapped geologic units or provinces.

The gamma-ray spectrometer measurements (fig. 6) indicate that most of the map area is relatively low in natural radioactivity (Metzger and others, 1973). Most of the overflown areas show natural radioactivity readings that correspond to less than l part per million of thorium. The highest, but still moderate, readings of a few parts per million of thorium, are over the maria and over the terra east of Langrenus.

Gravity measurements, which were made only on the near side and limb regions, indicate gravity anomalies (mascons) in excess of 200 milligals in Mare Crisium (Sjogren and others, 1972) and Mare Smythii (Sjogren and others, 1974). The mascons are similar to those of other near-side circular basins and may be inter- preted as a result of an isostatically uncompensated disk of basaltic fill in these basins (Sjogren and others, 1972). Negative gravity anomalies occur in nine craters 100 km in diameter or larger. These mass deficiencies are consistent with uncompensated loss of material from the crater-forming impact (Geochimica et Cosmochimica Acta, 1973).

Apollo 15 subsatellite magnetometer data (Russell and others, 1973) indicate that the lunar field over most of the map area exhibits an average radial component in the range 0.4 to -0.4 gammas. Higher readings (0.8 to 0.4 gammas) are found within and east of the crater Humboldt. Two lower values (-0.4 to -0.8 gammas) are southeast of Tsiolkovsky, in the crater Subbotin and northeast of it. The sources of the lunar magnetic field are not yet well defined.

## STRATIGRAPHY AND INTERPRETATION OF UNITS

Most geologic units mapped here are defined as on a geologic map of the near side of the Moon at the same scale (Wilhelms and McCauley, 1971). The lower size limit for mapping units is 20 km across rather than the 10 km used on the near-side map. An important departure is the introduction of the Nectarian System. Materials deposited before the formation of the Imbrium basin, called pre-Imbrian on the near-side map and on other previous lunar geologic maps, are here divided into the Nectarian System and the informal pre-Nectarian (Stuart- Alexander and Wilhelms, 1975). Materials of and stratigraphically above the Nectaris basin, but below those of the Imbrium basin, are classed as Nectarian. Materials formed before the Nectaris basin are pre-Nectarian. Morphologic characteristics of Nectarian and pre-Nectarian craters can be determined where they contact the extensive ejecta blanket (Janssen Formation) and secondary-crater clusters of the Nectaris basin (southwest map corner); elsewhere craters are correlated by morphologic comparison

## CRATER MATERIALS

In mapping crater materials, additional departures from conventions of the near side map (Wilhelms and McCauley, 1971) are: (1) boundaries are extended out- ward to include more faintly textured rim materials and satellitic crater clusters; (2) most crater materials that would have been designated “pre-Imbrian undivided” on the near side map are here assigned to the pre-Nectarian, some to the Nectarian; (3) previously undivided Imbrian crater materials are divided into upper Imbrian (map unit $Ic_2$) and lower Imbrian ($Ic_1$) materials. (4) Copernican crater materials are not divided because albedo data or high-resolution photographs are lacking for part of the area. Petavius B, Giordano Bruno, and Necho are probably late Copernican; the bright, extensive, overlapping rays of the latter two craters were inappropriately termed the “Soviet Mountains” (Barabashev and others, 1960; El-Baz, 1972a); (5) the few irregular craters are not mapped separately from clusters and chains, which they generally resemble.

Most large, detail-rich circular craters are interpreted to be of impact origin Moreover, an impact origin is affirmed for the less distinctive craters mapped on the near-side map as “undivided pre-Imbrian” and here mostly as pre-Nectarian because their frequency distribution fits an impact model. Their subdued appearance is probably due to impact erosion and mantling. However, certain other craters that lack the rough rims, radial ejecta, and deep floors characteristic of impact craters seem too restricted in size range and distribution to be degraded impact craters. These are the usually double-ringed craters (map unit Irc) of subequal size (20–60 km) that are concentrated in the Smythii basin. They are commonly the sites of young, dark, presumably volcanic deposits (map units EId and $Im_2$).

Several crater floors are traversed by cracks. Three of these are mapped as a geologic unit (material of furrowed crater floors) because their uniform appearance suggests that they consist of a distinct material, probably volcanic or impact melts. Where cracks cut across units they are more likely of tectonic origin (probably rebound), and the floors are not mapped as a distinct unit; such floors occur in Humboldt, Petavius, Gauss, Cleomedes, and several smaller craters.

Many craters are grouped in clusters and chains of similar, apparently contemporaneous individuals (map units pNcc, Ncc, Icc, Isc). Most are probably of secondary impact origin. Distribution and morphology show that most Nectarian-age clusters and chains are secondary to the Nectaris and Humboldtianum basins; some in the southeast quadrant are secondary to Milne and Schrödinger (320-km diameter basin south of map area). Chains and clusters of pre-Nectarian age are radial to the Crisium basin and could be remnants of its secondary impact retinue, as could a chain at lat 15° S., long 65°E. (Hodges, 1973a), here mapped as Nectarian. Map unit Isc includes clusters that are satellitic to recognized primary impact craters of Imbrian age and are almost certainly their secondary impact craters. Some of these clusters are distant from the large craters but are identified as secondary by their morphology. Other conspicuous Imbrian- age chains, a few clusters, and some irregular craters are mapped separately (map unit Icc) because identification as secondary impact craters is uncertain. Most of these are in the north, and are radial to the Imbrium basin; they could be part of its outer secondary impact field. Some chains and clusters could be volcanic, as could a few small irregular craters that contain possible volcanic material (for example at lat 25° S., long 103° E. (Ncc) and lat 39° S., long 129° E. (Icc).

## BASIN MATERIALS

Young basins display two or more concentric mountainous rings, hilly material between the inner rings, a hummocky to lineated ejecta blanket beyond the outermost conspicuous ring, and clustered secondary craters in and beyond the lineated ejecta blanket (Baldwin, 1963; Stuart-Alexander and Howard, 1970; Wilhelms, 1970; Hartmann and Wood, 1971; Wilhelms and McCauley, 1971; Howard and others, 1974; Moore and others, 1974). Basins in the mapped area show these features to a degree dependent on basin age, size, and later cratering and other modifications. Impact basins and craters are probably gradational members of a size continuum in which the number of rings is proportional to feature size (Stuart-Alexander and Howard, 1970).

Basin materials are assigned ages according to whether they are believed to have been thoroughly fragmented and redeposited by the impact or merely dis- placed in more or less coherent masses by uplift or horizontal thrusting. (In both cases, radiometric ages of contained rocks may be relicts or pre-basin impact or igneous events.) Redeposition is believed to have produced the lineated textures of the basal Nectarian Janssen Formation around the Nectaris basin (Stuart-Alexander, 1971) and the probably younger lineated material (map unit Nbl) around the Humboldtianum, Milne, Mendeleev, and Moscoviense basins. On the other hand, the high peaks of the concentric basin rings are believed to be massifs of prebasin rock uplifted when the basin formed, perhaps overlain by considerable basin ejecta. Consequently these peaks are pre-Nectarian in pre-Nectarian basins (map unit pNbm) and both Nectarian and pre-Nectarian (map unit NpNbm) in Nectarian basins. Gradational, but generally less coarsely structured, rugged terrain of the rings and of circumbasin lower areas is similarly dated (map units pNbr and NpNbr). The origin of these units is uncertain, however, and they could consist mostly of redeposited ejecta or impact melt. The principal concentrically structured, hummocky, craterlike rings of the small Milne, Mendeleev and Moscoviense basins-probably include ejecta and thrust material; this material (map unit Nb) is gradational with the lineated ejecta and is assigned the same age. The Nectarian and pre-Nectarian age assigned to the extensive, nondistinctive mantled terra material (geologic map unit NpNt, concentrated in province tm) reflects its probable origin as a mixture of degraded ejecta of Nectarian and pre- Nectarian basins and craters.

The relative ages of the Nectaris, Humboldtianum, and Crisium basins are only partly established. Humboldtianum is believed younger than Nectaris because of its somewhat lower density of superposed craters (Hartmann and Wood, 1971) and its extensive sharp-textured ejecta and secondary crater clusters (map unit Ncc). The prominence of these features is especially significant because Hum- boldtianum is the smaller basin (600 km diameter of the main ring versus 850 km for Nectaris). Nevertheless Humboldtianum could be pre-Nectarian because an old-appearing crater (Belkovich) lies within the basin north of the map area Lucchitta, in press). Crisium displays many youthful features and is probably the youngest of the basins here considered pre-Nectarian. Its rim (units pNbm and pNbr) is more rugged than the other basin rims, including that of Nectaris (out- side the area). There are some Crisium radial lineations (in unit pNbr) and, as noted, some possible secondary impact chains. Crisium is nevertheless considered older than Nectaris and Humboldtianum because these lineations and chains are relatively rare in spite of comparable basin sizes; the most conspicuous ring of Crisium is 500 km in diameter and the outermost high ring has a 680 km diameter Wilhelms, 1973).

Other pre-Nectarian basins are also relatively dated by morphologic freshness. density of superposed craters (Hartmann and Wood, 1971), and presence or absence of surrounding mantled terra deposits. These criteria suggest the following ascending order of formation of pre-Nectarian basins:* Tsiolkovsky-Stark, Al-Khwarizmi-King, Lomonosov-Fleming, Australe, Marginis, Fecunditatis (or Fecunditatis, Marginis), Smythii, Serenitatis, and Crisium, followed by the Nectarian basins Nectaris, Humboldtianum, Moscoviense, Milne, and Mendeleev.

## OTHER TERRA MATERIALS

Light-colored deposits that form plains or that mantle and subdue terra are widespread in the area, though less common than on the central near side. On the basis of density and morphology of superposed craters, the plains materials are tentatively divided into three gradational units (of middle Imbrian, early Imbrian or late Nectarian, and Nectarian age), and the less distinct terra-mantling materials are divided into two (of Imbrian and Nectarian age). Each deposit may consist of accumulated layers of more than one age capped by the mapped unit.

Evidence is growing for an impact origin of plains and mantle materials, once widely believed to be mostly volcanic. Rocks collected from plains at the Apollo 16 site outside the map area are impact breccias (Apollo Field Geology In- vestigation Team, 1973). They could be ejecta from the Imbrium or Orientale basins or both (Eggleton and Schaber, 1972; Chao and others, 1973; Moore and others, 1974). Imbrian plains and mantles in the map area could also be of this origin in spite of their great distance from the two basins (Chao and others, 1973; Moore and others, 1974). Extensive Nectarian-age plains and mantles surround the lineated ejecta blankets of the Nectaris and Humboldtianum basins and could be distal ejecta of these basins, as could more distant patches. Extensive patches of plains material of Imbrian and Imbrian or Nectarian age between Petavius and Humboldt could consist partly of ejecta of these craters. The ejecta could be clastic, or some plains could be impact melt, as proposed for young plains near the crater King (Howard, 1972). However, a volcanic origin cannot yet be excluded for all occurrences. For example, Imbrian-age plains in the Lomonosov-Fleming basin seem too concentrated to be the deposits of basins or craters.

A furrowed and pitted unit resembles hilly and pitted and hilly and furrowed units on the near side (Wilhelms and McCauley, 1971), including the Descartes material at the Apollo 16 site. Additional, unmapped occurrences are suggested by widely spaced furrows near Pasteur (El-Baz and Roosa, 1972) and by textures faintly visible on some poor photographs. The near-side occurrences were interpreted before the Apollo 16 mission as terra volcanic materials, but the returned rocks apparently are impact breccias in which original igneous textures have been severely altered (Apollo Field Geology Investigation Team, 1973). The Soviet spacecraft Luna 20 landed in a large furrow-dominated patch in the map area (lat 3° 22' N. long 56°33' E.) and apparently returned material like that collected at the Apollo 16 site (Vinogradov, 1972; Wilshire and others, 1974). This suggests that the furrowed and pitted unit was emplaced by impact. It may be composed of basin ejecta and other material that has been peppered by secondary impacts from craters and basins. Possible sources of the secondaries north of Mare Marginis include the craters Gauss, Lomonosov, and Neper, and the basins Humboldtianum and Orientale; the latter is exactly antipodal to the occurrence and a theoretically reasonable source (Moore and others, 1974). The Imbrium basin is a possible source for the northwest-southeast belt south of Mare Crisium. Internal origin remains possible, however, especially for occurrences with fissures and faults, as in the Smythii basin and between Crisium and Fecunditatis.

In summary, an impact ejecta origin is preferred for the plains, mantles, and furrowed and pitted materials because of the results of the Apollo 16 and Luna 20 missions. However, the distribution, stratigraphic relations, and morphology of these units remain consistent with internal origins.

## MARE AND OTHER DARK MATERIALS

Two units of mare material are mapped, older and younger. These materials are darker than any terra plains, and some have ridges typical of near-side mare units. Surface missions, including Luna 16 in the map area (lat 0°42' S., long 56° 18' E.; Earth and Planetary Science Letters, 1972), have established that the mare materials are basaltic.

Most of the older unit occupies the Australe basin (Stuart-Alexander and Howard, 1970). Its age is established by superposition of the ejecta blankets and satellitic crater fields of the craters Humboldt and Jenner, both of which contain or are embayed by the younger mare unit (for example see photo IV-12H at lat 36° S., long 88° E. where Humboldt secondary craters overlie the older unit and are partly flooded by the younger unit). This overlap of mare material by Imbrian crater materials is rare on the Moon and suggests that the older mare unit is older than most or all near-side mare material.

In the absence of clear stratigraphic relations, the two units are distinguished by density of small superposed craters. The older unit is mapped in the Marginis basin and in large craters in and near the Lomonosov-Fleming basin (see photo IV-17H to compare the two mare units and light-colored plains and terra units). With less certainty, it is mapped in some patches around the Humboldtianum and Crisium basins, where photographs are of marginal value for crater studies. The younger unit seems to have the cratering characteristics of near-side mare material of late Imbrian age, although many of the smaller patches could be older or younger.

Several types of nonmare dark materials are present (unit EId) that could be post-Imbrian. In Mare Smythii, some material has fresh-appearing flow lobes and hummocks, and thin, sparsely cratered dark material is superposed on the unusual multiple-ringed craters or surrounds fresh-appearing rilles that are probably its source. Between the craters Scaliger and Titius (lat 26° S., long 102° E.) the unit consists of hummocky dark material rent by fresh-appearing fissures. The surrounding mare material also appears young, being sparsely cratered and containing sharp wrinkle ridges and distinctive lava benches. This dark complex and Smythii may be the youngest volcanic centers in the map area. In other places a mantle darkens and slightly subdues densely packed Humboldt secondary craters (lat 31.5° S., long 89° E.—see IV-12H). This dark mantle and those inside several large craters may be thin beds of mare lava or a pyroclastic facies of mare material. The dark material in Waterman (lat 26° S., long 128° E.) could also be volcanic or could be impact melt ejected from Tsiolkovsky.

## BRIGHT SWIRLS

Swarms of light-colored sinuous markings (stipple pattern on geologic map), which resemble the Reiner gamma feature on the western near side (McCauley, 1967), occupy an irregular area in and around Mare Marginis (El-Baz, 1972b). They seem to have no intrinsic relief and are visible on mare material, several terra units, and both the floors and rims of craters. They are bright like crater rays, but no certain source craters have been discovered. No plausible theory of origin is readily suggested. They may be caused by chemical alteration of the surface materials by gases released from the lunar interior (El-Baz, 1972b), or they may be ray materials, perhaps from Giordano Bruno or a smaller unmapped impact crater on the north rim of Goddard (lat 17° N., long 90° E.), deposited in a sinuous pattern by unknown processes.

## GEOLOGIC HISTORY

After a period of crustal formation about which little is known, a rain of large and small impacts created a dense array of overlapping craters and multi-ring basins whose remnants are now exposed in a topographically high, “primitive” terra. These include very old craters and the basins Tsiolkovsky-Stark. Al- Khwarizmi-King, Lomonosov-Fleming, and probably unidentified others.* Six other basins formed during this period are large enough or young enough to retain rugged rims and traces of their surrounding ejecta. The formation of basins and craters are the only recorded events of pre-Nectarian time.

The Nectarian Period was initiated by a large impact west of the mapped area that created the Nectaris basin, blanketed the pre-Nectarian crater-and-basin terrain with lineated and probably nonlineated ejecta, and created clusters of secondary craters. A similar, but probably later, impact created the Humboldtianum basin north of the mapped region, and smaller impacts formed three other basins and numerous craters.

Like the Nectarian Period, the succeeding Imbrian Period began with a large basin-forming impact outside the mapped region. Traces of this Imbrium impact may be present here as plains and terra-mantling materials and perhaps as crater clusters and furrowed and pitted terrain. Alternatively some of these materials may have been produced by volcanism or structural dislocation during this or later times. Another massive impact, on the western limb of the Moon, created the Orientale basin, whose ejecta may also have influenced this region.

Sometime during the Imbrian Period, perhaps before the formation of the Orientale basin, basaltic volcanism created dark mare plains in some of the pre-Nectarian and Nectarian basins and craters. This early volcanism was followed in later Imbrian time by more widespread basaltic volcanism in the same and other basins and craters, including some craters of Imbrian age. Before and during this late Imbrian mare volcanism, impacts decreased drastically in number and continued at a much lower rate during the Eratosthenian and Copernican Periods up to the present.

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Geology mapped 1971-72. Data sources: Lunar Orbiter and Apollo photographs, plotted on coverage map, courtesy of National Aeronautics and Space Administration; X-ray fluorescence data courtesy of I. Adler, Goddard Spaceflight Center, NASA; gamma-ray data courtesy of A.E. Metzger, and laser altimeter data courtesy of W.L. Sjogren, Jet Propulsion Laboratory, California Institute of Technology. Brightness data from Apollo 8 and Apollo 17 Hasselblad frames taken during trans-Earth coast.

Adjoining geologic maps at same scale: near-side map by Wilhelms and McCauley (1971) overlaps between lat 32° N., and 32° S. west of long 70° E., and between lat 32° and 48° N., and S., west of long 58° E.; central far-side map by Stuart-Alexander (1977) adjoins east map boundary; north-side map by Lucchitta (1977) overlaps north of 45° N.; south-side map overlaps south of lat 45° S.

Geologic maps at the 1:1,000,000 scale entirely or partly within area by Stuart-Alexander (1971), Casella and Binder (1972), Hodges (1973a, b), Grolier (1974), and Olson and Wilhelms (1974).

Work performed on behalf of the National Aeronautics and Space Administration under contract Nos. W-13,130 (mapping; Wilhelms) and NGR 09-015-206 and T-1167B (integration of remote sensing data; El-Baz).

Shaded relief base charts; 2d edition, October, 1970, prepared by Defense mapping Agency, Aerospace Center (formerly Aeronautical Chart and Information Center, U.S. Air Force), St. Louis, Mo. 63118. West of long 100° E., Lunar Earthside Chart (LMP-1); east of long 80° E, Lunar Farside Chart (LMP-2). Dots refer to center of named feature. Some feature names shown on these charts have been deleted here. Names shown are selected from the approved International Astronomical Union (IAU) list of 1970, with the addition of Al-Khwarizmi (lat 7° N., long 107° E.) and Necho (lat 5° S., long 123° E.), names approved by the IAU in 1973

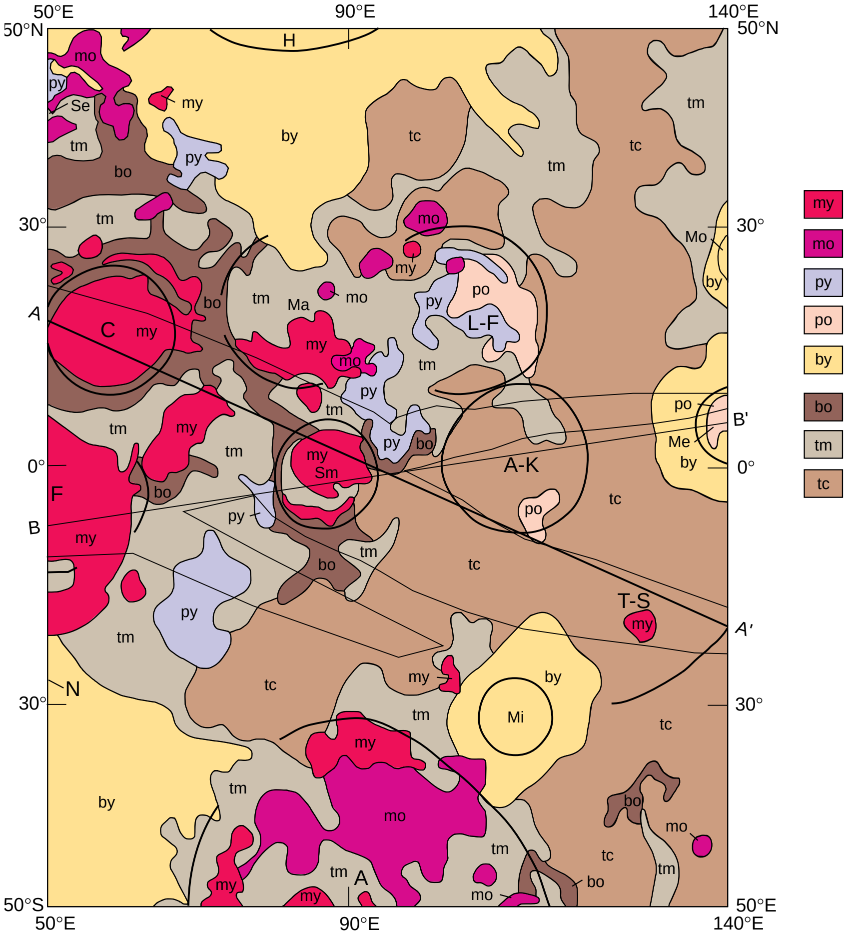


Figure 1. Geologic provinces—areas characterized by concentrations of a geologic unit or of units related in age and origin. Mare provinces larger than 50 km across and other provinces larger than 200 km are shown. Nectarian and younger crater materials are included in provinces that are inferred to lie beneath them.

| | |
|---|---|
| my | Mare, young (units Eld and $Im_2$) |
| mo | Mare, old (unit $Im_1$) |
| py | Plains, young (units Ip,It, and INp) |
| po | Plains, old (unit Np) |
| by | Basins, young (units Nb, Nbl, Nj, Ncc, Nt where adjacent to preceding units, NpNbm and NpNbr) |
| bo | Basins, old (units pNbm and pNbr) |
| tm | Terra, mantled (units INfp, Nt except as above, and NpNt) |
| tc | Terra, cratered (units pNt and pNc) |

A-A' and B-B', lines of laser altimeter profiles and diagrammatic geologic cross sections (figs 2, 3). Outlined areas, geochemical coverage (figs. 4, 5). Main rings of basins are shown; shown:identifying letters indicate approximately basin centers where possible: A, Australe; A-K, Al-Khwarizmi–King; C, Crisium; F, Fecunditatis; H, Humboldtianum (centered off map); L-F, Lomonosov-Fleming; Ma, Marginis; Me, Mendeleev; Mi, Milne: Mo, Moscoviense (centered off map); N, Nectaris (main ring off map); Se, Serenitatis (main ring off map); Sm, Smythii, T-S, Tsiolkovsky-Stark.*

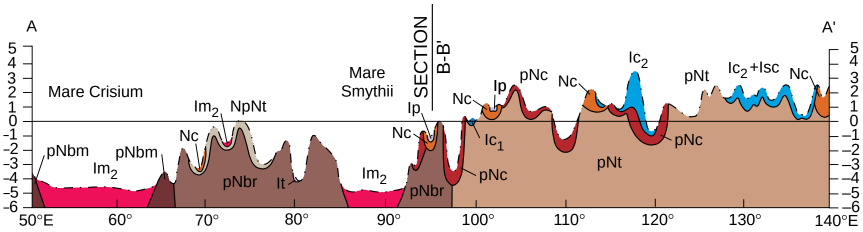


Figure 2. Apollo 15 laser altimeter profile and diagrammati geologic cross section (A–A' on geologic map and fig. 1). Ve tical exaggeration 55:1. Dots indicate laser measurements connecting lines are interpolations based on inspection photographs. Elevations referenced to a sphere of 1,738 k radius around the center of mass. Geologic units that occup less than 20 km along line of section not shown. Where line section intersects a crater interior, upper part of inferred su floor brecciated rock shown as crater material.

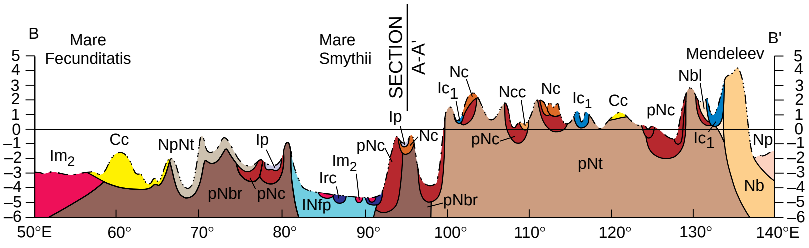


Figure 3. Apollo 16 laser altimeter profile and diagrammatic cross section (B–B' on geologic map and fig.1). Constructed as in figure 2.

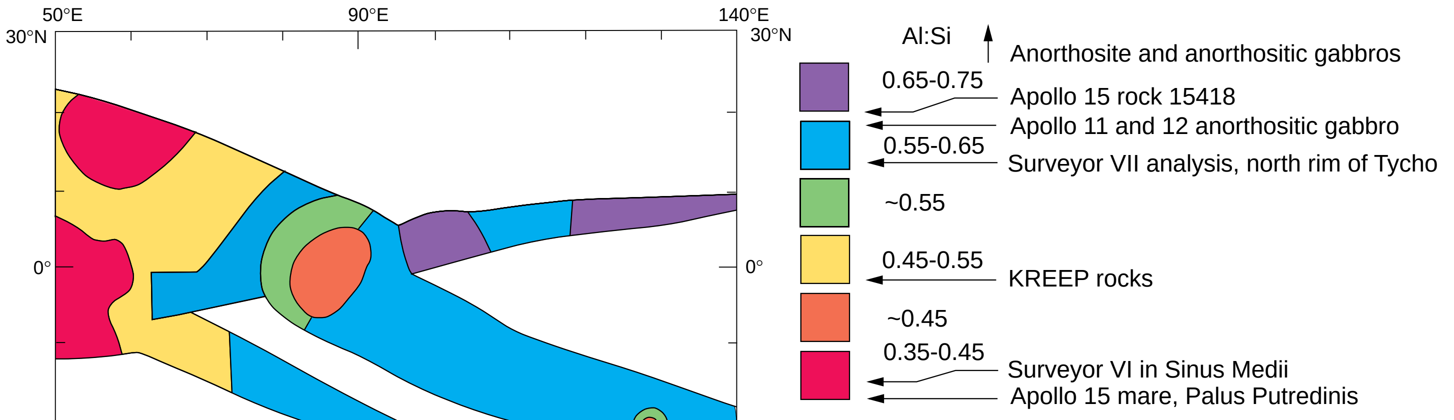


Figure 4. Concentration ratios of aluminum to silicon measured by the Apollo 15 and 16 orbiting X-ray spectrometers (Adler and others, 1973). Rock analyses shown for comparison (Adler and others, 1972, p. 2165).

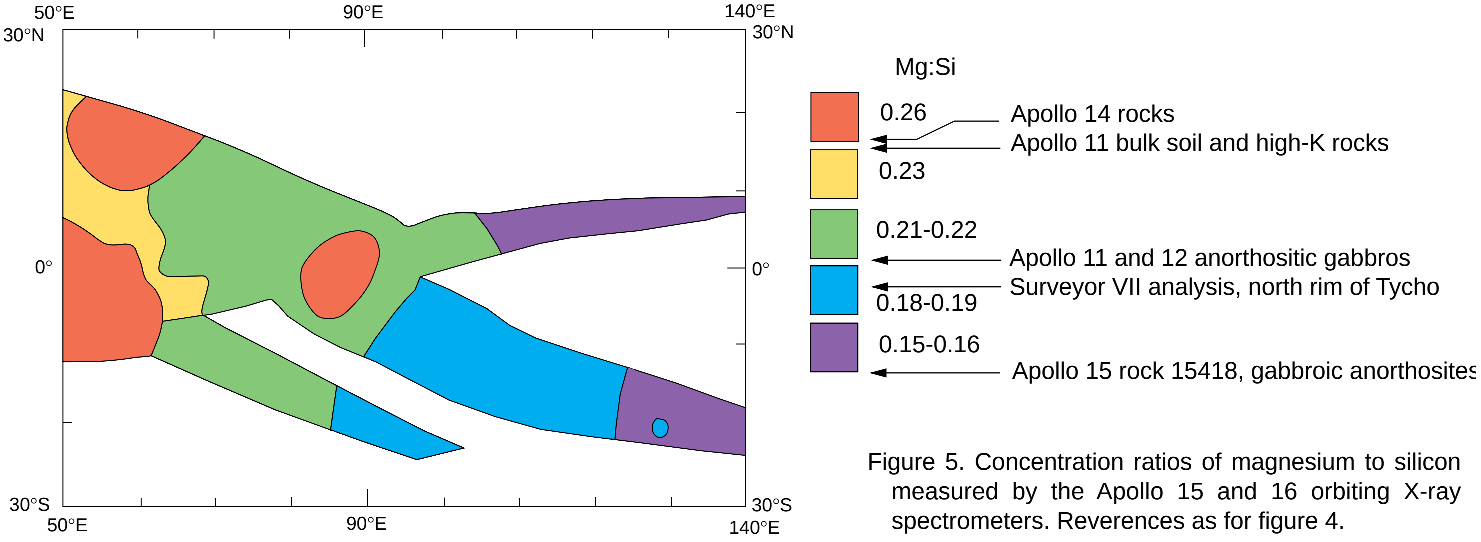


Figure 5. Concentration ratios of magnesium to silicon measured by the Apollo 15 and 16 orbiting X-ray spectrometers. Reverences as for figure 4.

**This version of FIGURE 5 supersedes the illustration printed on the map**

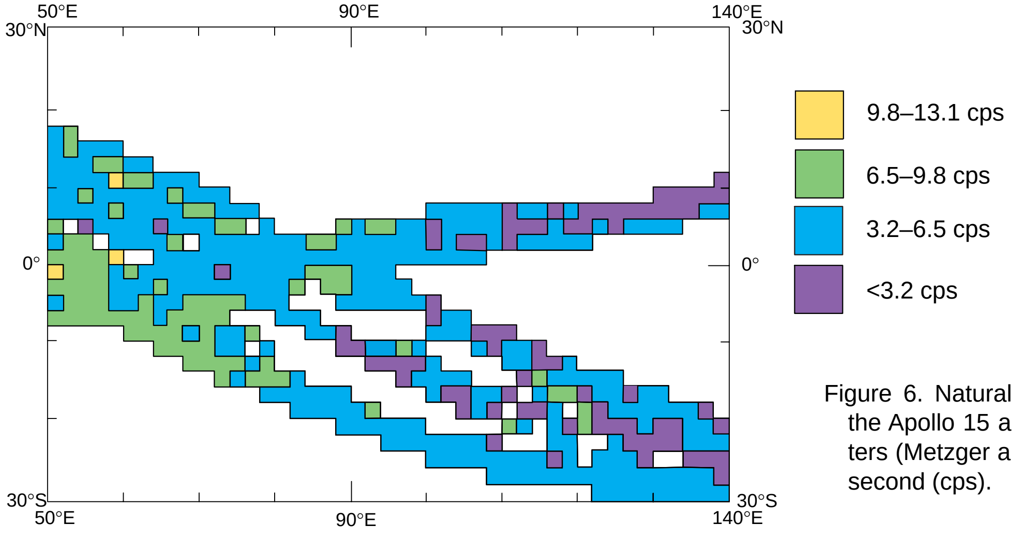
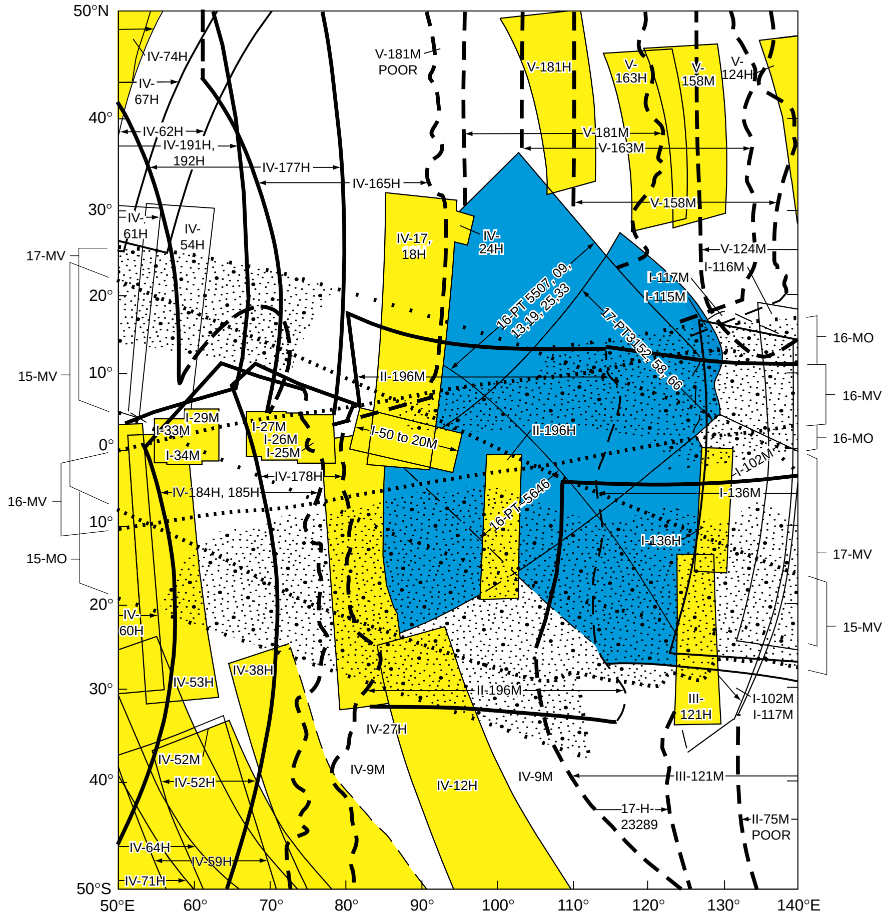


Figure 6. Natural gamma-ray emissions measured by the Apollo 15 and 16 orbiting gamma-ray spectrometers (Metzger and others, 1973). Units are counts per second (cps).



# PHOTOGRAPHIC COVERAGE

Solid lines, actual edges of photographic coverage. Dashed lines, approximate limits of useful coverage. Dotted lines, outline of Apollo orbital coverage. Unbarbed ends of arrows indicate that additional coverage extends beyond line. Heavy outlines and numbers indicate miminum nearly complete coverage (13 frames).

I to V: Unmanned lunar Orbiter photographs. H, high-resolution frame; M, medium-resolution frame. Frames with best definition shown in yellow.

15, 16, 17: Apollo mission photographs. MV, vertical metric, and MO, oblique metric phoographs taken from orbit; PT, panoramic camera photographs taken during trans-Earth coast (shown in blue); H, hand-held Hasselblad photographs. Shaded areas, orbital coverage taken at low sun-illumination angles (<45°).

Individual frames (PT) shown on map and strips of frames (MV, MO) listed below are the minimum necessary to cover area with some overlap; within a strip, alternating frames normally provide complete stereoscopic coverage and every fourth frame normally provide complete monoscopic coverage. Photographs taken at low sun-illumination are listed in italics.

15–MV
*300-315*: 316-378
*880-903*;904-957
*1564-1596*;1597-1640
*1852-1883*; 1884-1918
*1946-1982*; 1983-2007
*2623-2658*; 2659-2672

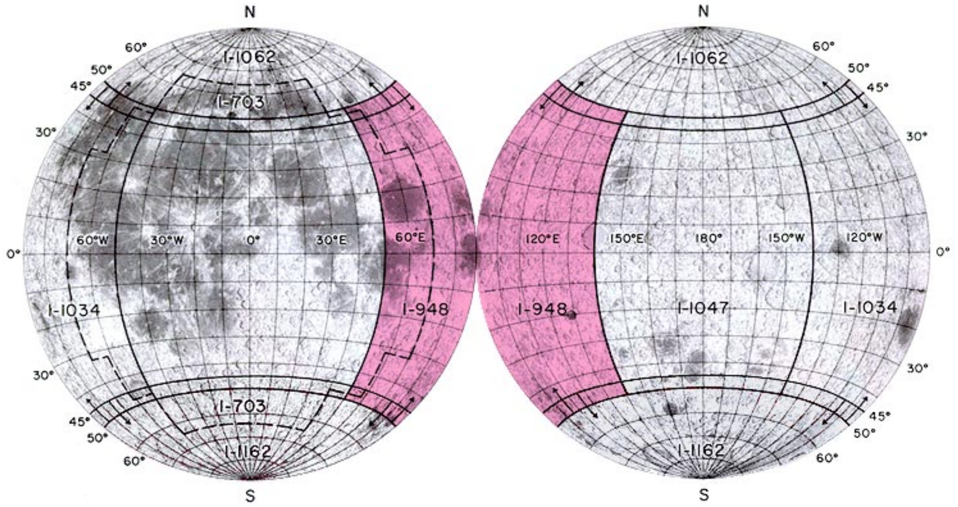
15-MO
*2694-2525*; 2526-2534

16–MV
*61-67*: 68-133
*1565-1585*;1586-1632
*2695-2734*;2735-2770

16-MO
*607-619* (lower strip)
*1304-1322*; 1323-1332 (upper strip)

17–MV
219-272: *273-295*
704-774;*775-780*
1713-1725
*1996-2018*; 2019-2073
*2597-2630*
*2795-2829*; 2830-2864

Wide-coverage photographs not plotted; Apollo 16 metric photographs, for example, frame 3023, taken during trans-earth coast give excellent overviews of most of area especially between lat 30° S. and 45° N., long 80° E. and 135° E. Lunar Orbiter frames IV-21M and IV-23M are useful north of lat 10° N. and between long 60° and 90° E. Hasselblad frames 8-H-2506 (color) and 17-H-23296, 23327, 23333, and 23341 are useful for comparisons of brightness over large areas



INDEX MAP OF THE MOON

The number preceded by I refers to published 1:5 000 000 geologic map

I-703 Geologic map of the Near Side of the Moon (dashed line) (Wilhelms and McCauley, 1971)

I-948 Geologic map of the East Side of the Moon (Wilhelms and El-Baz, 1977)

I-1034 Geologic map of the West Side of the Moon (Scott and others, 1977)

I-1047 Geologic map of the Central Far Side of the Moon (Stuart-Alexander, 1978)

I-1062 Geologic map of the North Side of the Moon (Lucchitta, 1978)

I-1162 Geologic map of the South Side of the Moon