INTRODUCTION

Lunar geology is mapped on the basis of the principles of stratigraphic sequence. Super-

position relations are determined and crater morphologies compared. The sequence of

stablished lunar time-stratigraphic system (Shoemaker, 1962; Shoemaker and Hackman,

1962; McCauley, 1967; and Wilhelms, 1970). The age of a crater is determined from several

geologic events can then be reconstructed, and stratigraphic units can be placed in the

Ray material

Characteristics

expression

Interpretation

up surface material

tions are referred to a spherical datum 2.6 kilometers below the mean radius to minimize minus elevation values. CONTROL The horizontal and vertical positions of features on this chart are based primarily on the positions of 150 lunar features measured by J. Franz and computed by Schrutka-Rechtenstamm. This control network is supplemented by ACIC extensions in localized areas. Additional horizontal positions have been selected from the Consolidated Catalog of Selenographic Positions by D. W. G. Arthur and the coordinates of 696 lunar features by R. Baldwin. The probable error of the control is evaluated at 1000 meters.

NAMES Feature names were adopted from the 1935 International Astronomical Union nomenclature system as amended by Commission 16 of the I.A.U., 1961 and 1964. Supplementary features are associated with the named features through the addition of identifying letters. Craters are identified by capital letters. Eminences are identified by Greek letters. Names of the supplementary lettered features are deleted when the association with the named feature is apparent. A black dot is included, where necessary, to identify the

exact feature or features named.

PORTRAYAL The configuration of the lunar surface features shown on the base chart is interpreted from photographs taken at Lick, McDonald, Mt. Wilson, Yerkes, Stony Ridge, Kwasan, and Pic du Midi Observatories. Supplementary visual observations with the 20 and 24 inch refracting telescopes at Lowell Observatory provide identification and clarification of indistinct photographic imagery and the addition of minute details not recorded photographically. The pictorial portrayal of relief forms is developed using an assumed light source from the West with the angle of illumination maintained equal to the angle of slope of the features portrayed.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AND THE North USAF AERONAUTICAL CHART AND INFORMATION CENTER Principal sources of geologic information: Lunar Orbiter IV photographs (shown on index map) with maximum useful resolution approximately 125 m and photographic Lunar base chart LAC 97, 1st edition, 1965, by the quality generally high except between longitudes 41° and 47°; high-illumination photo-USAF Aeronautical Chart and Information Center, graphs 5818 and 5819, 61-inch reflector, U.S. Naval Observatory, Flagstaff, Arizona; St. Louis, Missouri 63118 low-illumination photographs, 61-inch reflector, Catalina Observatory, University of LUNAR ORBITER IV HIGH-RESOLUTION COVERAGE OF FRACASTORIUS QUADRANGLE INDEX MAP OF THE EARTHSIDE HEMISPHERE OF THE MOON Number above quadrangle name refers to lunar base chart (LAC series); number below refers to published geologic map GEOLOGIC MAP OF THE FRACASTORIUS QUADRANGLE OF THE MOON

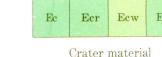
Interpretation

PREPARED IN COOPERATION WITH THE

Mare material Dark mantling material Low-albedo material that covers patches of plains Level, generally featureless plains of low albedo; large area in Mare Nectaris has sharp sinuous and other terra, and subdues some craters. High incidence of subdued small irregular craters ridges. Very few superposed craters; fills in low Volcanic material from local sources such as the Interpretation Basaltic lava flows. Some may grade into Imbrian irregular craters, possibly thin lava flows or ash of different composition than light mantling material mare Mare material Material of craters with convex floors Similar to Eratosthenian mare except slightly higher Craters with convex floors having meniscus-like albedo and generally more superposed craters contacts with walls; some with irregular cracks or rilles; rim crests distinct to quite sharp; albedo Basaltic lava flows. Abundant Copernican rays intermediateIcf, crater material, undivided may have led to misidentification of some Eratosthenian mare. Locally may grade into Eratosthenian Icfr, rim material. Relatively smooth; partly bumpy around Bohnenberger Icfw, wall material. Smooth, steep slope, uneven depth; albedo slightly higher than rest of crater Icff, floor material. Convex; concentrically ridged in small craters, crosscutting irregular rilles and minor mounds in Bohnenberger Probably volcanic craters; some may be impact craters flooded with lavas Irregular-crater material Terra mound material Two irregular craters. draping thickly over part Large, relatively shallow crater near Fracastorius eastern part of quad-K: subdued-appearing Plains-forming material rangle; forms low, hemisbut superposed on lower Characteristics pherical tumescent Imbrian crater; rough Forms level plains, sparsely to moderately cratered; interior with smaller mounds approximatelyalbedo intermediate, similar to adjacent terra. Fills 5 km in size. Albedo crater (ridge crest sym bol) on floor. Colombo E extensive low-lying areas in central third of quadintermediate and locally is deeper with uneven rangle and floors many pre-Imbrian and early Imhigh where material floor and sharp break at brian craters. Locally grades into unit pIts. covers crater walls all-floor interface Separated from some mare by low irregular escarp-Interpretation Volcanic material, posment gradational with other mare Crater near Fracastorius sibly fields of cinder Interpretation Ignimbrite, lava, debris, or mixture of these. Much K probably volcanic crater: Colombo E may may be old mare material lightened through age. only have volcanic floor May locally contain some pre-Imbrian and post-Imbrian plains materials Irregular-crater material Semi-level terra material Characteristics Fairly extensive areas of subdued, semi-level, low-Craters irregular to semi-rectangular, genlying, cratered terra; locally slightly rolling or with erally shallow; no distinct floors. In south small subdued hills; locally grades into unit pIth  $and\ southeast\ part\ of\ quadra\, ngle$ Interpretation Similar in origin to Imbrian plains material except Probably volcanic older and therefore more heavily cratered and modified by tectonic events; probably contains more im-**----**\_\_\_\_\_ Lineament Mare ridge crest Inferred fault Contact Dashed where approximately located or Dashed where approximately located; dotted Linear feature, chiefly shallow groove  $Barbs\ point\ down\ slope$ where buried. Ball on line indicates narrow Interpretation ---+----+---graben; bar and ball on apparent down- Zone of weakness; may be joint, fracture, aries are gradational and some are also very approximate). Queried where phothrown side. Offsets a unit or forms scarp or fault with sense of movement undeter-Ridge crest tography poor. Dotted where concealed; against which younger rocks are deposited mined. Locally grades into graben Linear ridges, mostly symmetrical buried unit indicated by symbol in parenCrater material

Material of rayed craters. Albedo generally high; rim crests sharp, inside walls steep, Streaks of patchy material with albedo higher than rim deposits extensive. Piccolomini L has anomalously low cooling rate during gouges in Mare Nectaris and clusters of smaller surrounding terrain. No detectable topographic penumbra (Shorthill and Saari, 1970) Cc, crater material, undivided. Craters > 10 km in diameter divided into: Ejecta from Copernican impact craters that churned Ccr, rim material. Forms relatively smooth surface from rim crest outward Ccw, wall material. Steep, smooth nenterraced slopes inside crater; albedo very high

Ccf. floor material. Small area relative to crater diameter; slightly convex; albedo high Interpretation Craters of impact origin. Sharpness and apparent freshness indicate youthfulness. High albedo and positive therma anomaly indicate exposure of fresh rock. Rim material, ejecta blanket thinning outuard; wall material, local bedrock with some slumps and colluvium; floor material, breccia, fallback, and some slump rock



Material of sharp, fresh craters without rays except that Cook G may have some faint rays; albedo intermediate to high; rim crests slightly less sharp than on comparablesized Copernican craters. Most craters > 5 km wide have one or more small craters Ec, crater material, undivided. Craters > 10 km divided into: Ecr, rim material. Relatively smooth around all except very faint radial pattern at

outermost edge around Piccolomini M, Piccolomini D, Reichenbach G, and Rosse Ecw, wall material. Steep, smooth unbroken slopes except slumped in Piccolomini D Ecf, floor material. Flat, smooth floors in most craters; small, sharp bumps in a few craters; in Piccolomini M convex, uneven, with large concentric hummocks and cracks Impact craters. Units interpreted as for Copernican craters except floor in Piccolomini M is probably all slump blocks



Light mantling material

Covers craters and rugged and hilly terra, subduing normally sharp features such as crater rim crests and filling in rough terrain. Albedo indistinguishable from surrounding terrain. In south central part of quadrangle Interpretation Probably volcanic ash

# Crater material

Crater features range from sharp to moderately subdued with decreasing crater size. Albedo mostly intermediate except on upper part of walls of most craters >10 km in Ic, , crater material, undivided. Moderately shallow craters, most lacking floors. Craters >10 km divided into: Icr., rim material. Appears smooth except for radially lineated area on south side of Monge. Recognizable collar about 1/10 crater diameter, except around Biot A and two largest craters, Monge and Neander, where it is 1/4 to 1/2 crater diameter Icw., wall material. Generally smooth except for terraces in Neander; less steep than in younger craters Icf., floor material. Flat to slightly convex; generally more extensive than in comparably-sized younger craters. Smooth in most; raised with elongate low mounds in

Icp<sub>2</sub>, peak material. Large light-colored mound in Neander Probably of impact origin. Rim, wall, and floor interpreted as for Copernican craters. Raised floor in Bohnenbærger C may be lava. Peak material structurally complex bedrock uplifted during creater-forming process

Bohnenberger C; small mounds and smooth, flat patches in Neander; large hummocks

Features less sharp than im comparable-sized upper Imbrian craters; most craters a little shallower with more crenulations and breaks in rim crest. Plains-forming material on many floors. Albedo intermediate, some slightly brighter patches on upper walls of Ic1, crater mat., undivided. Some shallow, bowl-shaped; others deeper with distinct floors Icr<sub>1</sub>, rim material. Narrow and quite smooth except around large crater Piccolomini where it grades outward into radial pattern Icrs, smooth rim material. Relatively smooth area on east flank of Piccolomini Icw1, wall material. Relatively smooth except for crenulations and well-developed terraces in Piccolomini. Less steep and deep than in younger craters Icf<sub>1</sub>, floor material. Hummocky in 20-40 km craters; level with small mounds in Icp<sub>1</sub>, peak material. Large, segmented mound in Piccolomini; gullied ridge in Reichen-

bach A; small, low mound in Reichenbach C Most craters probably of impact origin. The small bowl-shaped craters resemble craters in lower Imbrian clusters and therefore may be isolated Imbrian-basin secondary craters. Rim and peak material as for upper Imbrian craters; smooth rim material probably more fluid part of ejecta blanket; wall material more colluvium and slumps, less bedrock than in younger craters; floor mostly slumped material

## Crater cluster material

Clusters of overlapping craters, either mostly 10-15 km wide and moderately subdued or 5 km or less and subdued; craters shallow without distinct interior break in slope. Elongation and overlap direction of most clusters approximately radial to Imbrium basin; a few clusters perpendicular to this direction. Identification uncertain for small queried craters in southeast part of quadrangle obscured by terra mantling material Most craters believed secondary impact craters of Imbrium basin because of consistent

radial alinement. Similar to abundant Imbrium secondary crater clusters in Maurolycus

## Crater material

quadrangle (Scott, 1971)

Crater features moderately subdued in largest craters, very subdued in small ones. Albedo intermediate, locally high on walls pIc3, crater material, undivided. Mainly shallow craters pIcr<sub>3</sub>, rim material. Mainly recognized by generally raised relief not by texture; numerous small superposed craters pIcw<sub>3</sub>, wall material. Terraces in all larger craters except Santbech are coalescent and indistinct. Channeled radially in a few craters pIcf<sub>3</sub>, floor material. Level to convex with subdued hummocks in most. Contact with wall mostly indistinct pIcp3, peak material

Most are probably impact craters. Units interpreted as for lower Imbrian craters

Crater material Crater features very subdued; rim crests rounded, irregular, and broken. Albedo intermediate and indistinguishable from surrounding terra pIc 2, crater material, undivided. Shallow, poorly defined; rim crests generally indistinct pIcr2, rim material. Mainly recognizable by relief; narrow band compared to younger craters. Abundant superposed smaller craters pIcw2, wall material. Terraces indistinct and incomplete pIcf<sub>2</sub>, floor material. Low mounds in Fracastorius; central peak in Reichenbach

Probably impact craters, although diagnostic features such as shape and type of floor

mostly obliterated. Units interpreted as for lower Imbrian craters

Hilly and rugged mountainous terra material Gently rolling to rugged terrain; uneven on a fine scale; steepest slopes tend to face Mare Nectaris, and in south and eastern part of quadrangle, the most mountainous terrain and basin-facing scarp forms a concentric belt around Mare Nectaris pIth, hilly relatively subdued uplands grading into: pItr, rugged mountains

\_\_\_\_\_

Slope

points down slope

Covered crater rim crest

Remnants of three concentric mountain rings and intermountain ejecta of Nectaris basin. Considerably subdued and mantled by younger deposits. Analogous to mountain rings and ejecta of Orientale basin (McCaulley, 1968). Greater ruggedness and completeness of outer ring compared to inner two appears typical of degraded circular basins (Stuart-Alexander and Howard, 1970). younger deposits

pIth, most is Nectaris ejecta; some probably subdued mountain rings; some inside inner ring may be basin floor material

\_\_\_\_\_ Narrow circular ridge in mare Drawn at base of steep slope; barb Imterpretation May be covered crater rim crest or may

Interpretation be structure related to mare material

. . . . . . . . . Approximate location of Nectaris basin mountain chain Approximate location of crest of inward Arrows point in direction of facing scarp of the three circular mountain down-slope movement

Janssen Formation

Present along southern border and

continuous with strongly lineated

terrain in Rheita quadrangle to

Nectaris basin ejecta blanket

(Stuart-Alexander, 1971)

south. Weakly lineated radial to

haracteristics

Nectaris basin

Interpretation

lines of evidence, but particularly from the morphologic criteria discussed by Pohn and Offield (1970), who studied crater morphologies on Lunar Orbiter photographs and correlated morphologic stages with the lunar time-stratigraphic system (Offield and Pohn, Crater cluster material 1970; Offield, 1971). Particularly pertinent to the understanding of geologic processes in the Mare Nectaris area, where this quadrangle is situated, are the features and sequence of Elongate clusters of overlapping 2-4 km craters and

craters elsewhere in quadrangle. Some smaller

craters very sharp and not necessarily overlapping.

Most clusters in Mare Nectaris radial to Theophilus;

Probably clusters of secondary impact craters radial

crater Fracastorius, may be secondaries of Tycho,

Crater cluster material

Mostly elongate clusters of overlapping craters; crater

sharpest. Craters shallow, without distinct interior

size varies from cluster to cluster, largest craters

Probably secondary impact craters. Small (1-2 km)

craters in long cluster north of, and radial to, Ne-

ander are secondaries; sources of other clusters un-

break in slope

to the primary crater. Other clusters, such as in

those in northeast radial to Langrenus

sources of a few clusters uncertain

Interpretation

formation of large, multi-ringed basins (McCauley, 1968; Stuart-Alexander and Howard, In general, only craters more than 3 km in diameter are mapped, and only those larger than 10 km are subdivided. However, very subdued craters in the 3-10 km range are not mapped, and few subdivisions are made if the units are less than 1 or 2 km wide. An earlier study of this quadrangle was made by Elston (1965). His work delineated some of the basic plains and crater units used here.

GEOLOGIC SUMMARY The multi-ringed Nectaris basin (Hartmann and Kuiper, 1962) dominates the Fracastorius quadrangle. The basin is 840 km across as measured from the outermost ring and lies athwart four quadrangles. Fracastorius, the southeastern quadrangle, straddles the three rings of the basin (fig. 1). In this quadrangle most pre-Imbrian structures and many deposits were formed by the Nectaris impact. Furthermore, the emplacement of many younger deposits was controlled by basin structures and locally by probable multi-ring structures related to the Fecunditatis basin centered northeast of the quadrangle. Other geologic features in the area include diverse mantling deposits and both primary impact craters and secondary impact craters produced by ejecta from distant impacts. Interpretation of the deposits and structures of this quadrangle is based partly on analogy with the very fresh appearing Orientale basin (McCauley, 1968) and on a Moon-wide study of large circular basins (Stuart-Alexander and Howard, 1970). The Orientale basin has three well-developed mountain rings with steep, inward-facing scarps, scalloped on a coarse scale. Rugged terrain at the top of the scarps slopes gently outward, grading into small pimply hills and finally passing under plains or mare material at the foot of the next scarp. A thick blanket inferred to be ejecta surrounds the outer mountain ring. The low inner basin is partly flooded with mare material younger than the basin.

FIGURE 1—Diagrammatic cross section from northwest to southeast across the Nectaris

basin structure; all craters have been omitted for clarity. Triangles represent probable

impact breccia of Nectaris basin The Nectaris basin is older, and although now highly subdued and modified (largely by superposed impact craters) it appears to have originally been similar to the Orientale basin. In the Fracastorius quadrangle, the three mountain rings are discontinuous and are not as obvious as they are in the Rupes Altai quadrangle to the west, where the prominent inward-facing Altai scarp marks the outermost ring. A jagged line of mountains continues from the Altai scarp arcuately across the Fracastorius quadrangle, roughly paralleled by remnants of the two inner rings. The low areas or inter-ring troughs, filled by plains or mare, are barely discernible in this quadrangle. However, the original circular shape of the inner basin is retained by the mare fill, and even though the large crater Fracastorius interrupts the basin, the mare has flooded the crater to a line approximately coincident with the foot of the innermost mountain ring. The mountain rings in the Fracastorius quadrangle are composed of a rugged terra unit with scarps facing basinward; the outermost ring has particularly bold relief. The rugged mountains grade into a hilly terra unit, analogous in position to the pimply hills of Orientale, and interpreted to be predominantly ejecta from the Nectaris impact subsequently degraded by erosion or covered by younger material. In the Imbrian basin, pimply material of the Alpes Formation occurs in corresponding positions and has been interpreted in a like manner (Page, 1970). The rugged terra may be partly mantled by ejecta, but its morphology is dominated by upthrown blocks and slices of pre-Nectaris bedrock. On the outer flank of the outermost and dominant ring, the rugged terra unit is covered by a weakly lineated terra unit, the Janssen Formation, interpreted as an ejecta blanket. This unit is more clearly lineated radially to the Nectaris basin in the Rheita quadrangle to the south (Stuart-Alexander, 1971). Impact cratering continued throughout the history of the quadrangle. The two largest craters are Fracastorius of middle pre-Imbrian age and Piccolomini of early Imbrian age. The most useful stratigraphic markers, however, are the oldest crater clusters; they are

clusters, which mark the base of the Imbrian System, give a strong southeast-trending Some irregular craters and a few craters with convex floors differ in appearance from the impact craters. The relative shallowness of the pre-Imbrian and Imbrian irregular craters suggests that these may be volcanic in origin (McCauley, 1968). It is interesting that the Imbrian craters with convex floors are restricted to the northern boundary of the area where mare material is most abundant; this suggests local internal control. Widely distributed level units range in age from late pre-Imbrian to Eratosthenian. The pre-Imbrian semi-level terra unit evidently filled low areas between the Nectaris mountain rings, local basins in the mountains, and possibly even the central Nectaris basin. The unit was probably level when deposited; prolonged cratering and rejuvenated faulting have roughened and tilted it. Imbrian plains material is smoother and less cratered, although in places the two units probably are intergradational. The Imbrian plains material continued to fill the same low areas and many younger low spots as impact cratering and degradation of the mountain rings continued. Contacts of these two units with other units are generally distinct and locally very sharp. However, in a few places, such as inside the crater Santbech and along the southeastern edge of Mare Nectaris, plains and mare material merge into each other and are differentiated only by a slightly higher incidence of craters on the light plains and by an albedo difference. These differences are similar to those that separate darker Eratosthenian mare from slightly lighter Imbrian mare and therefore suggest that some plains may be mare lightened by aging. All plains materials must have been emplaced in a fairly fluid state, and a great number of local volcanic sources is indicated by their wide distribution in disconnected patches. Similarity of the pre-Imbrian semi-level terra suggests that it, too, was primarily volcanic deposits to which impact debris has been added. Mare rocks, which compose the upper Imbrian and Eratosthenian low-albedo level units, are concentrated in the northern third of the quadrangle, apparently because of the regional

radial to the Imbrium basin and are interpreted to be secondary craters of it. These

depression at the intersection of the Nectaris and Fecunditatis structures. Locally the emplacement of mare appears to have been controlled by the Nectaris mountain rings, but in other places mare cuts across the rings. The mare materials in the Fracastorius quadrangle are interpreted to be basaltic lavas because all mare rocks sampled to date, including those in Mare Fucunditatis, have basaltic compositions (Turkevich and others, 1968, 1969; Lunar Sample Analysis Planning Team, 1970; Lunar Sample Preliminary Examination Team, 1970; Luna 16 press releases, 1970). Various Imbrian and Eratosthenian mantling units are also interpreted as volcanic. Of particular interest is the sparsely distributed terra mound unit that drapes over a few craters and forms tumescent mounds, obscuring or obliterating features that appear sharp in other parts of the same crater. The morphology of this unit contrasts with that of the ubiquitous level units which filled depressions, suggesting that it was originally more vis-

cous. It is mapped as Imbrian because it occurs on an upper Imbrian crater, but older, degraded mound material would be very hard to distinguish from pre-Imbrian hilly terrain. Also contrasting with the level units are two mantling units that seem to form a thin veneer on a variety of terrain, subduing the underlying features; they may be layers There are many linear elements in the quadrangle. Most of the prominent inferred faults are approximately concentric with the Nectaris basin. Some faults and lineaments paral-

lel the early Imbrian crater clusters. Still other faults and lineaments trend northeast and may be part of the lunar grid (Fielder, 1961; Strom, 1964). The youngest features in the quadrangle are the ray systems. Local ray patterns surround small Copernican craters and long, feathery rays emanate from distant craters such as Tycho and Stevinus A. The rays represent ejecta and churned-up surface material.

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