NORTH-POLAR LUNAR LIGHT PLAINS: AGES AND COMPOSITIONAL OBSERVATIONS. U. Koehler[1,2], J. W. Head III. [1], G. Neukum[2], and U. Wolf[2]; [1]Brown University, Department of Geological Sciences, Box 1846, Providence RI 02912, USA (uli.koehler@dlr.de), [2]DLR, 12484 Berlin, Germany.

Abstract: Varying surface ages of lunar light plains in northern-nearside latitudes indicate an origin of these smooth terrae units not exclusively related to Imbrium and/or Orientale impact ejecta and subsequent processes. Multispectral data seem to support a more diversified history for many of these plains.

Introduction and Background: Nature, ages, stratigraphic position, composition and mode of emplacement of lunar light plains have been discussed with controversy for over three decades. Covering about 5 percent of the lunar terra surface, the relatively low-albedo plains are the most distinctive terra landforms after the more craterlike ejecta of the fresh basins [1]. Morphological properties, like their smoothness, lower crater densities, their superposition on the "Imbrian Sculpture" and frequent occurence as crater fill, are mare-like. Other features, such as relative (compared to mare basalts) high albedo and geological/stratigraphical setting, are more highland-like. Not surprisingly, light plains were seen as both volcanic and impact related deposits (summarized in [2]). The Cayley Plains, a type locality in the central-nearside highlands, has been choosen as the landing site of the Apollo XVI mission partly to help resolve these interpretations. The astronauts collected samples—highly brecciated rocks—and concluded that the Cayley was indeed of impact origin [3, and subsequent reports in *A16 PSR*]. These findings have been extrapolated to stratigraphically similar plains units on the nearside, focusing on the Imbrium and Orientale impacts as responsible events for resurfacing terrae environment to form light plains [4]. In addition, theoretical modelling mechanisms have been provided that could explain how basin and crater ejecta were able to make up for the smoothness of light plains by stirring up local material through secondary-impact related processes [5, 6], or mega-impact induced seismic shaking [7].

However, subsequent age determinations showed that some light plains can not be correlated to the Imbrium or Orientale event [8, 9], the last two basin-forming impacts to occur on the Moon that had the ability to resurface areas thousands of kilometers away from their target site. An unknown form of highland volcanism was proposed as a contributing process in light plains formation. The question remained unanswered whether processes other than impact-related were responsible for the formation of these enigmatic geological units, and how these processes might have worked. Focusing on light plains in the northern-nearside highlands, a chronological approach has been chosen to address these questions, and compositional information from multispectral data has been included to support our investigations.

Surface Ages: Mapping the northern-nearside light plains, earlier workers have recognized the stratigraphically and morphologically obvious bimodal distribution of smooth terrae units north and northeast of Mare Frigoris [10]. The older of these plains (Ip_1; based on stratigraphic relations and surface-crater densities) show gradual transition into (Imbrium-impact) Fra Mauro Formation units, whereas the younger unit (Ip_2) cannot be related to this relatively nearby-impact event. Instead, it was proposed that the impact of Orientale, despite the fact it is several thousand kilometers away, could have smoothed these terrae units with its ejecta stirring up local highland material [4], an interpretation that seems to be not compelling as these younger plains show quite homogeneous surfaces over extended areas. Determining precise surface ages of smooth surface units should help getting a chronology of plains emplacement in these latitudes.

Based on the principle of crater-frequency distribution measurements and adjusting the cumulative crater-frequency distributions to a lunar standard distribution [11], and "fixing" the Orientale and Imbrium event with the absolute ages obtained by radiometric measurements of Apollo samples [12] to this distribution, one is able to determine reliable absolute age data for surfaces after measuring the crater-frequency distribution on it. As the decline in impact frequency is rather steep during the first billion years in lunar history, the discrimination between surfaces of different age can be determined to a relatively high degree of reliability.

Fourty five smooth plains areas north and northeast of Mare Frigoris have been mapped for crater-frequency counts. Some light plains have been disturbed by secondary cratering impact to a degree that made deduction of reliable age data impossible, so only 27 crater counts yielded useful absolute ages. A histogram of how these plains ages are distributed is shown in fig. 1. For reference, the Imbrium and Orientale events are marked at their respective time of impact at 3.90 by, and 3.84 by, respectively [13].

There are several observations that can be made in this distribution: 1.) The ages do not cluster around one or two peaks, instead, the majority of light plains formed in a rather broad time span between 4.0 by and 3.65 by. 2.) There are some light plains that seemed to have formed before the Imbrium impact event. 3.) Light plains formation peaked at the time of, or shortly after, the Orientale impact event. 4.) Light plains formation continued a significant time span after the Orientale basin impact. 5.) There are light plains ages that are remarkably younger than the age of the Orientale basin, exposing surface ages that are only slightly older than the mare-basalt ages of their neighbouring units at the eastern margin of Mare Frigoris. 6.) The time span of light plains surface formation seems to extend from around 3.95-4.0 by. to 3.60-3.65 by. In addition, there seem to be correlations between ages of light plains and their geographic position; oldest ages, >3.90 by., occur in the vicinity of the north pole, in and surrounding the craters Byrd, Main, Scoresby, and north of Anaxagoras. Plains with Imbrian-impact ages as young as Orientale impact are clustered in and around craters Meton, Barrow, Barrow K, Baillaud, east of W. Bond, and Neison. Ages that are clearly younger than the Orientale impact can be found in the extended smooth plains area west, south and southeast of crater Gärtner, northeast of Epigenes, east of De Sitter, Barrow K, and the areas bordering the eastern margin of Mare Frigoris. Except for the suspicious correlation between geographic occurence and absolute ages, the statistic pattern of light plains ages is fairly well comparable to that of the central-highland's (Cayley Plains) units [14], where especially light plains of ages younger than the Orientale impact can be found—but in that case in no direct contact relations to mare units.

Multispectral Data. In order to get additional information on the light plains areas that have been selected for crater statistics, multispectral data have been investigated from the 2nd Earth/Moon encounter of the Galileo spacecraft (December 1992) which had excellent viewing geometry of the area of interest [15]. Based on previous work [16] it could be confirmed that the north-polar plains indeed show distinctive albedo behavior—being clearly brighter than maria, but darker than highland units, and showing less albedo variation than highland. Well exposed mare-basalt units, and well exposed unambigous highland areas have then been chosen to extract reference spectra in order to get clues to plains affinities. A number of fresh young craters in the light plains environment have been chosen to "sample" the material that is covered by the mature regolith. There are three interesting observations to report: 1) There are light plains showing clear highland affinities; 2) there are light plains that show definite mare affinities; 3.) the occurence of these two groupings is confined to areas in greater distance from Mare Frigoris for the first, and close to Mare Frigoris for the latter "spectral" group. In an ongoing process, application of spectral-mixing models to Galileo and Clementine multispectral data should help answering fundamental questions on compositional aspects here.

Conclusion: Based on the absolute ages of light plains surfaces, the formation of these geologic units cannot be attributed to a uniform process. The fact that there are plains both clearly younger and older than the two largest last basin-forming impact events of Imbrium and Orientale, respectively, excludes an impact-ejecta origin related to these events—although Imbrium and Orientale ejecta deposition and their subsequent effects may certainly have played a major role in plains formation. Varying spectral characteristics con-firm that probably more than a singule process is responsible for the forming of these terra plains. As for the younger plains, it could be suggested that Late Imbrian craters contributed ejecta deposits to cover existing early mare basalts (making up for the smoothness of these surfaces) in the eastern Frigoris area, but the scarcity of dark-haloed craters does not support this idea—further investigations in these directions are necessary. The wide timespan of about 300 my in plains ages further towards the north pole also requires a more detailed look at compositional aspects; due to some morphological evidence, unidentified forms of highland volcanism should be kept in mind, as it is known that non-mare volcanism occured elswhere in the Imbrium viciniy, on the Apennine Bench [17], forming a large unit of terra plains there.

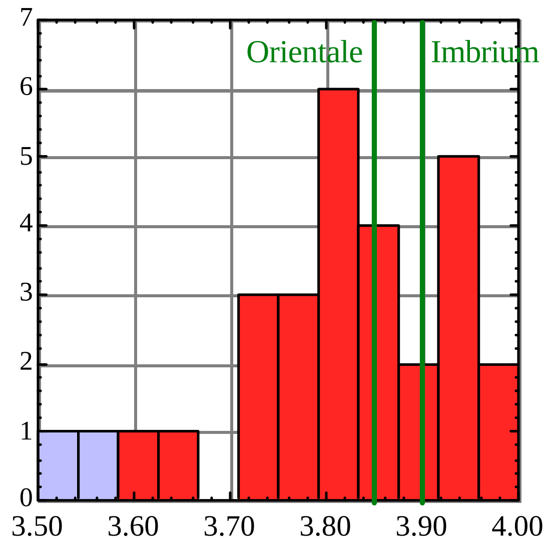

Fig. 1—Frequency (y-axis) of light plains ages (x-axis, billion years) in the northern-nearside hemisphere. Note that the two youngest ages (blue) are surfaces of mare-basalt units in eastern Mare Frigoris, adjacent to light plains units. Time of Imbrium, respectively Orientale event are given as reference.

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